HABILITATION THESIS

ADVANCES IN OPTIMIZATION OF MANUFACTURING AND REMANUFACTURING PROCESSES

HABILITATION THESIS

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To my mother and father,

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Summary

This habilitation thesis represents a synthesis of my academic achievements obtained after receiving the PhD degree in Control Engineering (2006). These achievements are based on a hard work carried out over the last 15 years of professional career.

The themes of my scientific research have coagulated around the Systems Engineering field, with emphasis on applied informatics in production systems.

Having the chance of accomplishing the PhD in collaboration with a French team and working within the framework of the Automatic Control Laboratory of Besançon, my research interest was pointing towards the study of a special class of production systems: automatic disassembly and remanufacturing systems.

In the context of the exponential development of consumer goods production, in particular that of electric appliances, electronic and auto-moto industry, the waste recovery and recycling require a precise logistics, intelligent systems for collection and storage of the end-of-life products and efficient disassembly, recovery and recycling management operations.

In this thesis, results of my research are graded after three main topics:

1. Optimization techniques in maintenance and manufacturing processes;
2. Optimization of the remanufacturing processes by disassembly planning, scheduling and balancing;
3. Implementation of some intelligent decision-making systems for the management of the reverse supply chains.

The scientific publications associated with these topics are briefly introduced on the first Part of the work. This contains four chapters and describes both the scientific achievements as well as the career development.

Chapter 1 presents the context and the reasons for the choice of the research themes.

Chapter 2 shows the impact of the scientific contributions from the academic point of view. Being part of Romanian and French groups of research, has brought me not only the practical experience and the professionally

accomplishment, but the international recognition in the field as well. This has increased with the multiplication of my scientific citations. Invitations into the scientific international committees and professional organizations, the international reviewer and international projects evaluator nominees have followed.

Chapter 3 of the thesis details the achievements in the didactic field.

Chapter 4 summarizes the scientific contributions organized by the three research topics. Some techniques for optimizing the manufacturing and the maintenance processes are listed in paragraph 4.1. Both combinatorial optimization techniques and metaheuristics applied in control of production systems are presented. At the same time, some complex methods of multicriteria decision aid are applied in order to evaluate the maintenance parameters.

Paragraph 4.2 synthesizes the research on the remanufacturing processes with emphasis on the study of automated disassembly lines. Here are detailed the problems that occur in the processes of disassembly planning, scheduling and line balancing. Taking into account that disassembly as a process is not the reverse of assembly, the main differences between the two industrial processes are emphasized. In disassembly, complications arise due to the unknown quality and quantity of the existing components in the end-of-life product. This provides the discrete character of process variables and from here the idea of their evaluation by implementing decision techniques in terms of uncertainty. Another challenge of the disassembly systems is the "depth" of the process: up to what level a product could be disassembled, so as its end-of-life value being maximized and the recovery or the recycling operations bring profit. In this context, the researcher must compare the total production cost with the results and profit, so that the disassembly process becomes effective from the economic point of view.

Paragraph 4.3 describes a relatively new theme of research, both on global and European plan, namely the optimization and control of the reverse supply chains.

In the context of the sustainable development, researchers from all over the world are interested to reduce the impact of the remanufacturing and recycling processes on the environment. In this paragraph several decision support instruments for the management of the reverse supply chains are proposed. These tools include artificial intelligence elements (intelligent agents, neural networks, Bayesian networks) that allow their integration into intelligent software that controls the reverse supply chains.

Part II of this thesis contains *Chapter 5* that details my academic development plans, both in research and education.

References are listed in the last part of the work.

I consider that the present habilitation thesis can be seen and consulted as a valuable bibliographical reference by the future PhD students in the field of Systems Engineering and in particular it is useful to those who direct their interest towards Reverse Engineering.

Rezumat

Teza de față reprezintă o sinteză a rezultatelor academice obținute după primirea titlului de doctor în Automatică (2006), rezultate care se bazează însă pe o muncă susținută desfășurată de-alungul a peste 15 ani de carieră profesională.

Direcțiile de cercetare științifică s-au coagulat în jurul domeniului Ingineriei Sistemelor, înclinând cu precădere către informatica aplicată în sistemele de producție.

Având șansa unei teze de doctorat în cotutelă cu Franța și lucrând în timpul doctoratului în cadrul Laboratorului de Automatică din Besançon, mi-am îndreptat interesul spre studiul unor sisteme de producție particulare: sistemele automate de dezasamblare și refabricație.

În condițiile în care producția de bunuri de consum, în special cea de aparate electrice, electronice și autovehicule se dezvoltă într-un ritm frenetic, recuperarea și reciclarea produselor uzate din aceste ramuri de producție necesită o logistică bine pusă la punct, un sistem inteligent de colectare și depozitare, dar și operatii eficiente de dezasamblare, recuperare, reciclare și gestionare a deșeurilor.

In aceasta lucrare, rezultatele cercetării sunt clasate după trei teme principale:

1. Tehnici de optimizare a proceselor de fabricație și mentenanță
2. Optimizarea proceselor de refabricație prin planificarea, ordonanțarea și echilibrarea liniilor de dezasamblare;
3. Implementarea unor modele și sisteme decizionale inteligente pentru gestionarea operațiilor din lanțul logistic invers.

Publicațiile științifice asociate acestor teme sunt prezentate pe scurt în Partea a I-a a lucrării. Aceasta conține patru capitole și descrie atât realizările științifice, cât și evoluția carierei didactice.

Capitolul 1 prezintă contextul și motivația alegerii temelor de cercetare.

Capitolul 2 arată impactul contribuțiilor științifice din perspectiva academică. Munca în colectivele de cercetare românești, dar și în cele franceze, mi-au adus nu numai experiență practică și împlinire pe plan profesional, dar și

recunoașterea internațională în domeniu. Aceasta s-a amplificat odată cu înmulțirea citărilor publicațiilor mele științifice. Au urmat invitații în comitete științifice internaționale și organizatii profesionale și dobandirea calităților de reviewer ISI și evaluator de proiecte internaționale.

Capitolul 3 al lucrării detaliază realizările pe linie didactică.

Capitolul 4 rezumă contribuțiile științifice organizate pe cele trei teme de cercetare.

Câteva tehnici pentru optimizarea proceselor de fabricație și mentenanță sunt prezentate în subcapitolul 4.1. Este vorba atât de tehnici de optimizare combinatorie, cât și de algoritmi metaeuristici aplicați în controlul și conducerea sistemelor de producție. Totodată, sunt prezentate metode complexe de analiză și decizie multicriterială aplicate în vederea evaluării și optimizării parametrilor de mentenanță.

Subcapitolul 4.2. sintetizează cercetarea proceselor de refabricație, cu accent pe studiul sistemelor automate de dezasamblare. Sunt descrise problemele care apar în procesele de planificare, ordonanțare și echilibrare a liniilor de dezasamblare dedicate produselor aflate la sfarșitul ciclului lor de viață. Remarcând faptul că dezasamblarea, ca proces, nu este inversul asamblării, în această secțiune se subliniază principalele diferențe între cele două procese industriale. În dezasamblare apar complicații datorate calității și cantității necunoscute de componente existente în produsul uzat. De aici și necunoscutele discrete ale procesului automat de dezasamblare și ideea de a le determina prin tehnici de decizie aplicate în condiții de incertitudine. O altă provocare o constituie « adâncimea » procesului de dezasamblare : până la ce nivel poate fi dezmembrat un produs, astfel încat valoarea sa de sfârșit de viață să fie maximă, iar recuperarea și reciclarea părților sau materialelor componente să aducă profit? În acest context, cercetătorul trebuie să compare costul total de producție cu profitul obținut, astfel încat procesul de dezasamblare și recuperare să devină eficient din punct de vedere economic.

Subcapitolul 4.3. descrie o direcție relativ nouă de cercetare, atât pe plan mondial cât și pe plan european și anume optimizarea și controlul operațiilor din lanțul logistic invers.

În contextul dezvoltarii durabile, sunt puse în evidență preocupările cercetătorilor din întreaga lume pentru micșorarea impactului proceselor manufacturiere, remanufacturiere și de reciclare asupra mediului inconjurător. De asemenea, sunt propuse și trecute în revistă câteva instrumente de asistare a deciziilor în managementul lanțului logistic invers. Aceste instrumente includ elemente de inteligență artificială (agenți inteligenți, rețele neurale, rețele Bayesiene) ce permit integrarea în softuri inteligente care monitorizează și controlează operațiile din lanțul logistic invers.

Partea a II-a a acestei teze conține Capitolul 5 în care sunt prezentate planul de dezvoltare a carierei științifice și didactice, precum și direcțiile viitoare de cercetare. În ultima parte a lucrării sunt enumerate referințele bibliografice.

Consider că lucrarea de față poate fi privită și consultată ca o referință bibliografică valoroasă de către viitorii doctoranzi din domeniul Ingineriei Sistemelor și în particular de cei care își îndreaptă interesul spre Ingineria Inversă.

Abbreviations

AC	Ant Colony
AI	Artificial Intelligence
BN	Bayesian Network
CG	Column Generation
CIM	Computer Integrated Manufacturing
DBN	Dynamic Baesian Network
DLBP	Disassembly Line Balancing Problem
DPN	Disassembly Petri Net
DSS	Decision Support Systems
DTO	Disassembly to Order
EOL	End-of-Life
EOQ	Economic Order Quantity
GA	Genetic Algorithms
GDSS	Group Decision Support Systems
IA	Intelligent Agents
IP	Interger Programming
LP	Linear Programming
NN	Neural Network
NP	Non-deterministic Polynomial-time
OEE	Overall Equipment Effectiveness
PCB	Printed Circuit Board
RAP	Route Allocation Problem
RL	Reverse Logistics
RNN	Recurrent Neural Network
RSC	Reverse Supply Chain
SE	Simulated Enterprise
SP	Spare Parts
TPM	Total Productive Maintenance
UML	Unified Modeling Language
WEEE	Waste Electrical and Electronic Equipment

Figures

Introduction

Manufacturing has played a crucial role during the evolution of man, but the most rapid evolution of manufacturing technologies and skills occurred during the last two centuries.

The computer has had an important impact on all manufacturing processes. Computer Integrated Manufacturing (CIM) gave birth to complex automation systems where the flow of production is computer controlled from the product design to its assembly. The role of the researcher is that in collaboration with engineers and experts, to find the best techniques and technologies that optimize each phase of the automatic process.

However, in the context of a sustainable development and of the new environment regulations, stronger links between research, innovation and production are necessary. The traditional way of manufacturing, where only natural resources and virgin materials are used to produce new products is unsustainable. Many countries have started programs and imposed regulations that require the manufacturers to collect used products and pass them by a process of selection, disassembly, recycling or remanufacturing. In remanufacturing, the collected end-of-life products are transported to a remanufacturing factory where they are disassembled into parts. Then, repair and replacement operations are performed over parts or subassemblies, to maintain the product general operational condition. Remanufacturing has advantages over other recovery options as recycling, or refurbishing. Parts of product or even the whole product is upgraded during the remanufacturing process.

In the last decade, the number of companies embracing the remanufacturing techniques has increased, due to the monetary and environmental advantages. Researchers have started to address their work in design, planning, scheduling, inventory or logistics management of the remanufacturing process.

In this context, my research work is directed towards optimization of manufacturing and remanufacturing processes for the consumer goods, electric and electronic appliances and automotive industry.

The present habilitation thesis reviews my scientific and didactic accomplishments after getting the PhD degree (in 2006).

Chapter 1 of the thesis describes the research themes choice context and motivation.

Chapter 2 lists the impact of the scientific contributions from the academic point of view. Academic recognition of my scientific expertize come with invitations in PhD juries, International Programme Committees and Professional Organizations membership, national prizes, invitations as reviewer of important ISI Journals and European project evaluator.

Chapter 3 of the thesis details the achievements in the didactic field. Books, chapters, some recent courses and lectures and personal didactic contributions are listed here.

Chapter 4 summarizes the scientific contributions organized by three research topics. Both combinatorial optimization techniques and metaheuristics are applied in control of production systems. Some multicriteria decision aid techniques are applied in order to evaluate the manufacturing and maintenance parameters. In other section of this chapter, the remanufacturing process with emphasis on the problems occurring in automated disassembly systems is analyzed. In the last part of the chapter, several decision support instruments that include artificial intelligence are proposed for the management of the reverse supply chains.

Chapter 5 details my academic development plans, both in research and education. Some further scientific developments and projects in the field of remanufacturing and reverse logistics are outlined.

The final part of thesis includes some conclusions regarding my scientific and didactic activity and lists the work references. Every reference whose author or co-author I am is bolded in the text of this thesis.

I consider that this habilitation thesis may represent a valuable bibliographical reference for those who direct their interest towards Reverse Engineering and Reverse Supply Chains.

PART I

PROFESSIONAL, ACADEMIC AND SCIENTIFIC ACHIEVEMENTS

Chapter 1
Classification of research

Three main topics could be found in my research work:

1. Optimization techniques applied in manufacturing and maintenance processes
2. Algorithms for planning, scheduling and control of the disassembly activity which is part of the remanufacturing process
3. Decision aid tools in reverse logistics

Some of my works are dedicated to problems of resource allocation, production scheduling, and operation sequencing which have to be optimized in the economic sense without violating certain constraints. Techniques like combinatorial optimization, linear programming or metaheuristics were proposed to solve these NP-hard problems. Not all the time these techniques gave the optimal solution, but an acceptable one, that ensures the efficiency of the process. Sometimes, the goal is to maintain an automated machine or a robot in operational condition without causing interruptions in the production flow. In this case, the maintenance and the inventory theory add more constraints to the mathematical model of the system.

Other papers reveal my preoccupations regarding the remanufacturing process, especially the phase of disassembling the end-of-life products. Polynomial, quadratic, exponential or genetic algorithms were proposed to deal with the computational complexity of the disassembly planning and scheduling activities and to manage the uncertainties occurring during these processes.

In the last but not least, decision aid tools that integrate artificial intelligence elements are proposed in some of my papers. Evolutionary algorithms, Intelligent Agents, Bayesian Networks or Neural Networks are used to deal with the multi-objective optimization aspect of controlling an automatic system.

Chapter 2
Impact of scientific contributions

2.1. Academic impact

Till present I have developed a sustained research activity reflected in publication of 3 technical books (one in an international edition), 2 chapters, 19 papers in journals and conference proceedings indexed in ISI Web of Knowledge and 31 papers in journals and conference proceedings indexed in international data bases (BDI). A significant part of this work was possible due to the PhD research fellowship offered by the French Government (2002-2005) and also to the collaborations over the years with some research teams from abroad universities (Paris 8 University and CNAM[1] Paris), and Romanian Universities (Valahia University from Targoviste, Lucian Blaga University from Sibiu).

At present, my scientific work is cited (excluding self-citations) in 50 ISI indexed papers and about 75 BDI indexed papers, the **h-index** being **8**. Moreover, most citations are in books and leading ISI journals in the field like: *“Remanufacturing Modeling and Analysis”*, CRC Press, Taylor & Francis, USA, 2012, *“Reverse Supply Chains - Issues and Analysis”*, CRC Press, Taylor & Francis, 2013, or in *“Journal of Environmental Management”* (IF=2,52), *“European Journal of Operational Research”* (IF=2,358*),* *“Computers & Industrial Engineering”* (IF=1,783), *“International Journal of Production Research”* (IF=1,47), *“The International Journal of Logistics Management”* (IF=1,46), *“Studies in Informatics and Control”* (IF=0,913), *“International Journal of Computers, Communications & Control*” (IF=0,746).

As international reviewer I constantly collaborate with ISI Journals as *“International Journal of Production Research”*, *“Studies in Informatics and Control”*, *“International Journal of Computers, Communications & Control*”; *“Journal of Manufacturing Systems”* (IF=1,682), or *“Proceedings of the Romanian*

[1] Conservatoire National d’Arts et Métiers

Academy" and with Conferences organized and sponsored by International Federation of Automatic Control (IFAC).

As a recognition of my expertize, I am member in several professional organizations as: Technical Committees **IFAC TC 5.2** (Manufacturing Modelling for Management and Control) and **IFAC TC 5.4** (Large Scale Complex Systems), **EWG-MCDA** (EURO Working Group on Multicriteria Decision Aiding), **EU/ME** (The Metaheuristics Community), **SRAIT** (Romanian Society of Automation and Informatics), **SRR** (Romanian Robotics Society).

2.2. Professional impact

Over the years my achievements were appreciated in my own Romanian collective of research, but also abroad. Thus, in 2007 and 2011 I obtained the MCF[2] qualification in France, quality that allows the recognition of the academic level as Associate Professor in this country.

In 2011, between March and August, I was Invited Professor at Paris 8 University, where I developed research work as well as teaching. In this period, I worked in the SYS-MCO project together with the French team and the PhD students. The objective of the project included the maintenance in operational condition of different automated machines.

I participated to the elaboration and submission of two FP7 proposals together with international research teams:

- SCOPE FP7-SSH-2010-2, Sustainable policy options for social and economic development in regions of the enlarged Europe and its neighborhood, (SCOPE), FP7 Proposal, no of submission: EPSS 266927
- MARS FP7-ICT-2009-4: Multi-Agent system for collaborative and cooperative heterogeneous Robots in non-Structured environments (MARS), FP7 Proposal, no of submission: EPSS 249039

As Associated Professor I was co-director of several PhD Thesis:

Florin Bobosatu: *Advanced Systems for Decision Aid,* 2009, Politehnica Bucuresti

[2] Maître de Conferences

Ana Suduc: *Advanced Interfaces for Decision Support Systems*, 2010, Academia Romana

Nouha Ghorbel: *Gestion des réapprovisionnements périodiques de pièces de rechange sous incertitudes pour le MCO de parcs de matériels : maîtrise du risque de rupture des stocks,* 2013, Université de Paris 8

As member in PhD juries in the field of System Engineering, I referenced the PhD thesis of Florin Bobosatu and Ana Suduc (in Bucharest), and Ionel Cristian Vladu and Ravigan Florin (in Craiova) in 2009-2010.

Another professional impact were the two national prizes that I received in 2008 from the Romanian National Council of Scientific Research (CNCS).

In 2014 I have been qualified as national ARACIS (Romanian Agency of Quality Preserving in Higher Education) evaluator. In 2015 I was member in the ARACIS jury for evaluation and authorization of Automatic program of study from "Constantin Brancusi" University, Targu Jiu.

Chapter 3
Didactic achievements

I am author and co-author of 5 books dedicated to students and edited between 2002 and 2014. Their content generally refers to programming: structural or object oriented type, visual programming or graphics design and different tests for exams.

Regarding the educational programs, I proposed and give four new lectures for students at the postgraduate and master levels:

- Java Programming Engineering (dedicated to the fourth year of study)
- DOT NET Programming (third year)
- Decision Support Systems in Manufacturing (fifth year)
- Advanced Technics for Manufacturing Optimization (sixth year)

Over the years I conducted more than 50 graduating projects working with students from the last year of study in Control Engineering field. Some of these students gained important prizes at the local and national contests which made me proud of them.

As Invited Professor in France, (2011) I worked fifth months with the French students from IUT Paris 8, which provided me a great experience in teaching and coordinating projects in the French language and allowed me to know better the French educational programs.

As I always have been interested in collaborations with European Universities, I initiated and realized few international ERASMUS programs with four Universities: Patras University from Greece, Franche-Comté University, CNAM Paris and Paris 8 University from France.

My didactic activity is still rich. I am always looking for new challenges for my students, in their theoretical and practical activity. I'm giving lectures in C++ Programming, Object Oriented Programming, Combinatorial Optimization Techniques, Java Programming, and Decision Support Systems.

Chapter 4
Research and publications

4.1. Optimization of Manufacturing Process

This section refers to publications dealing with optimization of manufacturing processes, especially automatized ones.

Nowadays, Computer Integrated Manufacturing (CIM) gives an integrated vision and analysis of the manufacturing process. Production planning, scheduling and control are phases of manufacturing that need intelligent tools to assist the process. Optimization of manufacturing process means measuring and optimizing the process parameters using computer programs to effectively plan, schedule and control this process. For example activities like manufacturing resource planning, resource allocation, production scheduling, operation sequencing have to be optimized in the economic sense without violating certain constraints. These problems are complex and often hard to solve (NP-hard) and the role of researchers is to find the appropriate techniques and tools to reduce this complexity and to find the near optimal solution.

As my interest as a programmer specialist lies in elaboration of software integrating decision tools, I took advantage of my knowledge to implement it in practical applications and in my research, proposing intelligent tools for collaborative decision making.

Therefore, my papers published after 2009 generally addressed to two different problems that I encountered in manufacturing processes: a) proposing optimization techniques for manufacturing and maintenance and b) conceiving tools for collaborative decision making.

4.1.1 Optimization techniques in manufacturing

Manufacturing is a vital source of wealth in every industrialized nation. For the control of manufacturing process by computer, machines have to be provided with special programs which ensure the plan, the schedule and the control of production. These programs integrate optimization modules which functions are based on special optimization algorithms and programming techniques. The role of researcher is to find the appropriate optimization techniques and to implement them in a computer language program.

This paragraph describes my scientific preoccupations in finding the proper algorithms for manufacturing optimization.

In discrete parts manufacturing, process planning involves the act of preparing a plan for the order of operations, machines, tools and parameters requirements to obtain the final product. This planning activity has no time associated with it. It is the process scheduling which take into consideration the time component. This involves the time ordered arrangement of a set of jobs to be processed on a set of machines to optimize the systems' performances. A job/task may have more than one operation. Scheduling could be deterministic or dynamic. Deterministic scheduling implies that all operational parameters are known in advance. The main difference between process planning and process scheduling is that scheduling is time driven while planning explains how the operational jobs flow.

Sequencing is the order in which activities are performed in a manufacturing system. Routes deal with the specific path taken to accomplish the various processes necessary for completion of a job. The manufacturing sequencing problem is a challenge for the planner since is directly related to both batch size and production capacity.

A large part of scheduling literature assumes that machines are available all the time. In **(Ziribi et al, 2009),** the Multi-Purpose Machines (MPM) Job-shop scheduling problem, where the machine maintenance has to be performed within certain time intervals inducing machine unavailability, is studied.

Two approaches to solve the problem are proposed. The first is a two-phase approach where the assignment and the sequencing are solved separately. The second is an integrated approach based on the exact resolution of the 2-job problem using the geometric approach.

The MPM job-shop (job shop with Multi-Purpose Machines) with availability constraints:

- There are *n* jobs to be processed on a set of *m* machines. Each machine can process at most one job at a time.
- Each job consists of a sequence of operations that must be accomplished according to its manufacturing process.
- Each operation can be performed by any machine.
- Each operation is non-preemptive, i.e., it must be accomplished without interruption. Moreover, we assume that machine is unavailable during giving periods corresponding to preventive maintenance.
- The starting times and durations of these tasks are fixed and known in advance.

The objective is to find a schedule, defined by the starting time and the completion time of each operation, with a minimum makespan[3].

The problem was solved in two phase approach:

1. First a heuristic (***Tabu search***) based on several priority rules was applied for route allocation;
2. Second, a ***Genetic Algorithm*** for the operations sequencing was utilized;

Tabu search is nowadays one of the most widespread search metaheuristics (Talbi, 2009). The use of memory that stores information related to the search process, represents the particularity of this optimization method. Tabu search works like a linear search algorithm but it accepts non improving solutions to escape from local optima when all neighborhood solutions are non-improving. To avoid neighbors previously visited, the method memorizes the recent search trajectory in a *tabu list*. At each iteration of the search, this list is updated. Introducing the concept of solutions features in the tabu list, we do not

[3] The **makespan** is the total length of the schedule

have to check all the previous visited solution, just those which hold an aspiration criterion. If the generated solution is better than one from the list, the list is updated with this solution.

In **(Ziribi et al, 2009)** (which co-author I am), the solution is described as a list of operations on their corresponding machines. A routing move is defined by the relocation of a critical operation (operation that belongs to the critical machine) to a feasible machine position. For a given solution, we consider every possible reallocation of every re-routable critical operation. The tabu list consists in (operation, machine) pairs. The choice of the move is based on the value of the maximum makespan value of the preemptive schedules.

In what it concerns the second phase of the optimization process, we exchanged an operation scheduled before a maintenance period with another operation which can begin before this maintenance period, but is scheduled after this one, for each unavailability period of the critical machine. All possible permutations are tested. The permutation minimizing the makespan is then selected.

The second proposed method is based on an extension of the geometric approach to deal with the machine availability and the flexibility property of the problem. The scheduling of MPM job shop can be represented in the 2-dimensional plane with potential obstacles that depend on the assignment of machines for the two jobs (figure 1)

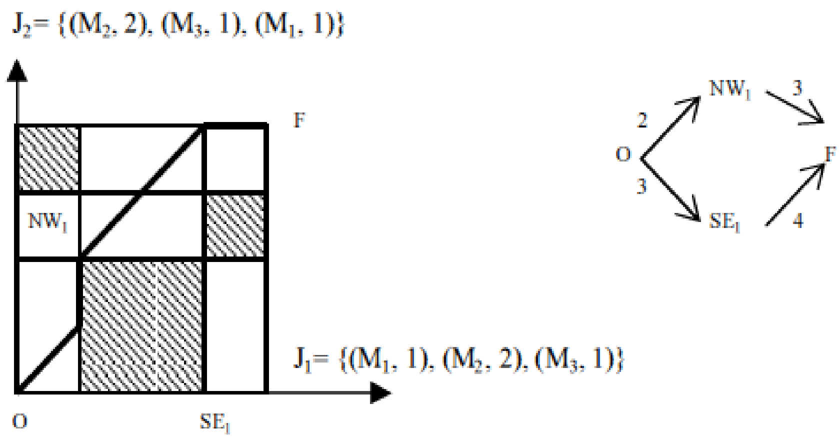


Fig 1 Geometric approach of the job shop problem with two jobs

(Aggoune, 2004)

We proposed a generalization of this job shop problem with availability constraints. Additional unavailability periods, corresponding to the execution of operations of the two scheduled jobs, are fixed on each machine. The algorithm is applied to the next two jobs of the sequence, taking into account the initial and the new unavailability periods. This procedure continues until all jobs are treated.

Simulation tests show that the first two-phase approach gives interesting results comparing with the integrated approach using the geometric representation. The main advantage of the two-phase approach is related to the computation time.

Another metaheuristic is applied in **(Zamfirescu et al., 2008),** where a bio-inspired approach to solve the route allocation problem (RAP) built into a decision support tool is presented. The solution is an extension of the Elitist Ant System (EAS) which includes many of the real life constraints that are dealt with in the daily scheduling process in transportation networks: the uniform distribution of routes diversity per vehicles, the average distance travelled in a certain period of time, the driver’s breaks between subsequent trips etc. Besides the algorithm's optimality, the approach allows to incrementally extend and adapt the constraints as the users discover new opportunities for improvements, shielding the software components (agents) to the complexity and dynamics of the route allocation problem.

Route allocation for the public transport is a complex and demanding task that pose many similarities with the scheduling process in manufacturing systems: vehicles are assigned on a daily basis to different timetables that describe routes according to the transportation lines, frequencies, transportation demand and travel times in the network.

The Route Allocation Problem (RAP) is inherently combinatorial and exact algorithms fail when the dimension of the problem (number of vehicles and routes) reaches a reasonable size. In addition, the problem is extended in real conditions (when new routes and vehicles becomes available) accounting for stochastic customer demand (the exact requested quantity is known only at travel time), accessibility restrictions (some vehicles encounter unpredictable delays and failures) and daily changing constraints (many optimization constraints are weighted and tuned on a daily fashion).

An ***Ant Colony*** optimization algorithm is applied to solve this problem. Ant Colony Optimization algorithm was introduced by Marco Dorigo, (2006) to solve so-called NP-hard class of optimization problems. Application of Ant Colony Optimization algorithm presents several advantages that are very attractive for the route allocation problem. The algorithm proved to have remarkable ability to produce a good suboptimal solution in a very quick time, responsiveness being a very important feature if it is implemented in a decision support system. Moreover, the algorithm preserves the versatility of the real ants, being able to deal with unforeseen situations when the vehicles availability and customer demands are rapidly changing.

In the case of RAP the environment is represented by a directed graph that reflects the hard constraints of the problem domain: the transportation lines which are fixed for a certain period of time. As a result, the nodes stand for a certain route in the transportation network, while the arches display the cost of allocating a vehicle to that route. Since the departure station for a vehicle may be virtually everywhere when the dispatching algorithm is operated, the graph includes an extra node connected to any potential route. In summary, the graph will have a number of nodes equal with the number of transportation lines served at one point in time plus a virtual route (figure 2)

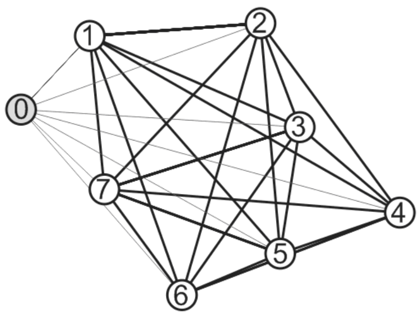


Fig 2. The graph used to represent the environment for the RAP.

The algorithm's behavior which converges to a near optimal solution by following a logarithmic performance function is represented in figure 3. This pattern is very common for the Ant Colony Optimization algorithms and demonstrates the feasibility of the proposed approach.

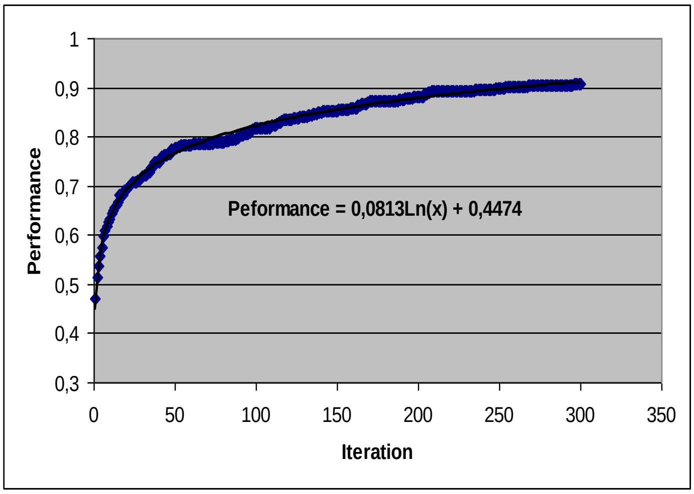


Fig 3 The performance of ant colony algorithm

An application of an ANN (*Artificial Neural Network*) of a RNRF type (Recurrent Network with Radial basis Function) in controlling a linear system is described in **(Patic et al, 2010).** The performance of ANN-based control solution is compared with a classic controller to show that ANN behaves better than the classic controller.

The used neural network is a variant of dynamic networks radial basis functions of dynamic RNRF: Recurrent Neural Networks with Radial Basis Function. The RNRF considers the time as an internal parameter of the network. This dynamical aspect is obtained by a recurrence of connections between neurons of the input layer. These self- connections provide the input neurons a capacity for taking into account of past input data. The neural network is equipped with two types of memories: a dynamic memory, for taking into account the dynamic data input and a static memory to store prototypes. The output layer represents the layer of Gaussian weighting (figure 4).

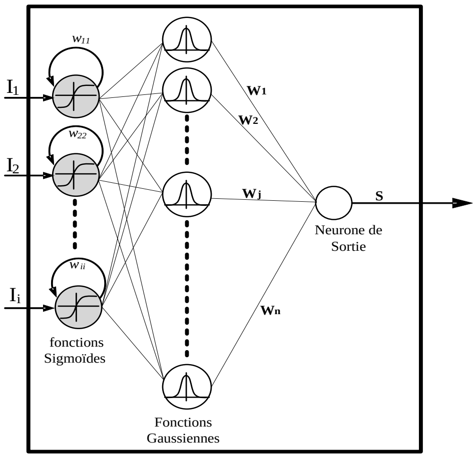


Fig. 4 RNRF Network

The learning process of RNFR involves two steps. The first is to define the number and the parameters of Gaussian functions. The method of k-means coupled with the method Min-Max is used. The second step is to calculate the weights of the connections of the output layer W by matrix inversion. This approach consists of using together a classical linear controller and a neural controller.

In **(Tchoffa et al, 2014**) the purpose of the study is to show that, to better manage the unavailability of an Information System, we must implement a Service Level Agreement (SLA) with a good system of measurement of Performance Indicators. The most important factor of the SLAs stability is the availability. In contrast, one has to study the unavailability of the human or machine interventions. The specification of a characteristic set requires a good working knowledge of this set. Figure 5 represents the SLA of Renault for operating and infrastructure support. Here, the indicator of quality analysis measures the availability in ten different areas (response time, availability of various platforms). In this context, the management of service levels has as objectives: to establish a customer supplier relationship between the IT department and users, to ensure better identification of needs in terms of services, to promote the balance between quality requirements and operating costs, to establish objective criteria for measuring the quality, to improve service quality and user satisfaction.

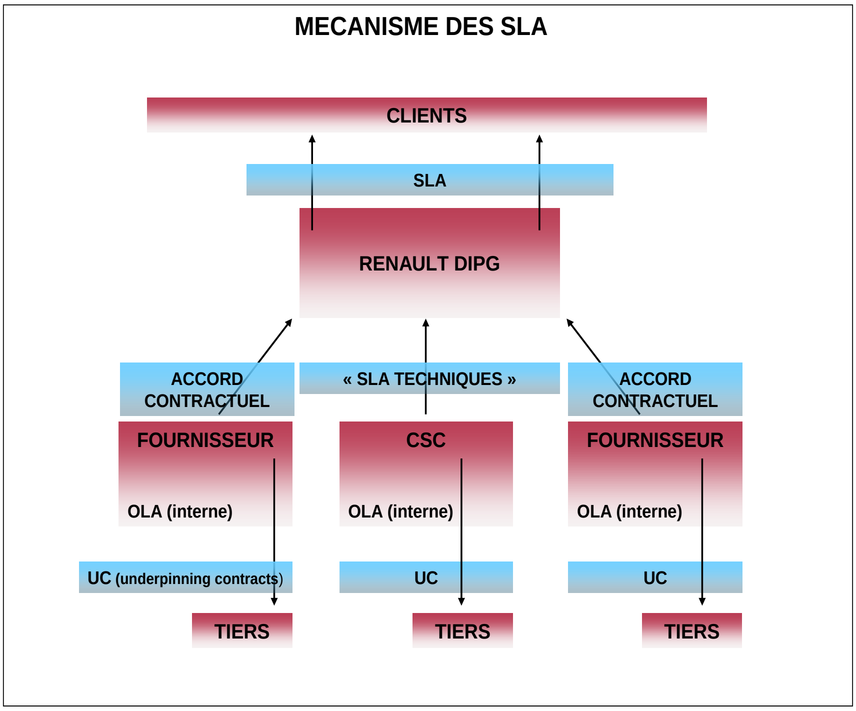


Fig. 5 Renault SLA

4.1.2 Optimization techniques in maintenance

In a manufacturing enterprise, the production department uses the equipment to manufacture various products from raw material and parts bought from suppliers. In a usual industrial scenario there are inherent wastes of materials and time. There are also other “invisible wastes” such as operating the machines below the nominal speed, start-up times, break downs of the machines and bottle necks. The maintenance department has a key role so as to ensure the continuous production flow by up-keeping the equipment at its normal functioning state. Total Productive Maintenance (TPM) is a concept that involves the entire company. The most important indicator to measure the efficiency of the TPM strategy is the Overall Equipment Effectiveness. Some of my papers propose decision aid models to improve the OEE indicator and the overall performance of the manufacturing line.

A method to optimize the OEE indicator is presented in **(Mainea, Duta et al, 2010)** starting from the definition of this parameter: OEE is the product of the availability, performance and quality of the equipment (Venkatesh, 2006).

$$OEE\% = Availability\% \times Performance\% \times Quality\%$$

Availability indicates the performance of the Maintenance Department and its value is given by the equation (1).

$$Availability\% = \frac{actual\ run\ time}{planned\ run\ time} \times 100 \qquad (1)$$

Where

actual run time = planned run time - idle time

Performance indicates the operator's performances and the way the equipment is used:

$$Performance\% = speed\ operating\ rate \times net\ operating\ rate \times 100 \qquad (2)$$

Where

$$speed\ operating\ rate = \frac{standard\ cycle\ time}{real\ cycle\ time} \times 100 \qquad (3)$$

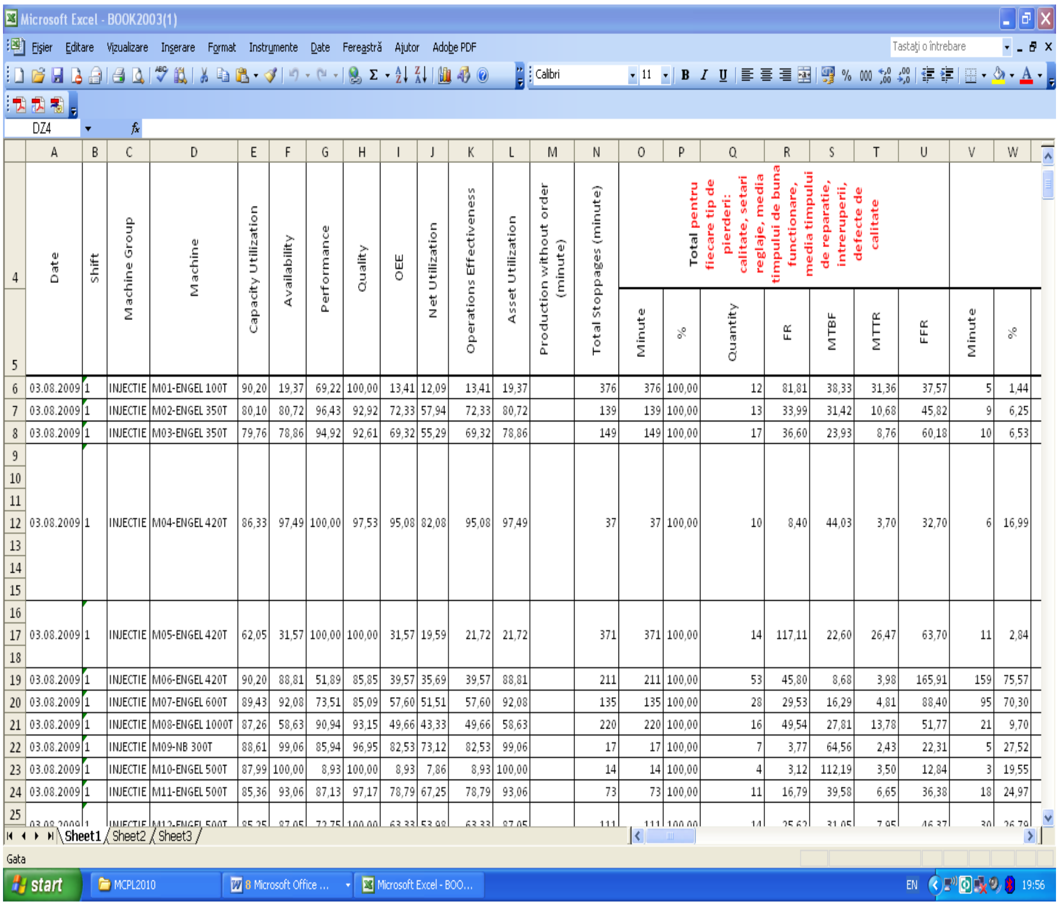
$$net\ operating\ rate = \frac{number\ of\ products \times standard\ cycle\ time}{actual\ run\ time} \times 100 \qquad (4)$$

Quality indicates the capability of the process:

$$Quality\% = \frac{quantity\ produced\ right}{quantity\ produced} \times 100 \qquad (5)$$

The proposed optimization method is to apply integer programming on a linear function that minimizes the idle time and the real cycle time from the equations (1) and (3).

The method was implemented in a Romanian Enterprise. The values of the necessary parameters to calculate the OEE are registered on line in Excel files like the one presented in the figure 6. These parameters are considered input data for our optimization method.



Date	Shift	Machine Group	Machine	Capacity Utilization	Availability	Performance	Quality	OEE	Net Utilization	Operations Effectiveness	Asset Utilization	Production without order (minute)	Total Stoppages (minute)	Total pentru fiecare tip de pierderi: calitate, setari reglaje, media timpului de buna functionare, media timpului de reparatie, intreruperii, defecte de calitate								
														Minute	%	Quantity	FR	MTBF	MTTR	FFR	Minute	%
03.08.2009	1	INJECTIE	M01-ENGEL 100T	90,20	19,37	69,22	100,00	13,41	12,09	13,41	19,37		376	376	100,00	12	81,81	38,33	31,36	37,57	5	1,44
03.08.2009	1	INJECTIE	M02-ENGEL 350T	80,10	80,72	96,43	92,92	72,33	57,94	72,33	80,72		139	139	100,00	13	33,99	31,42	10,68	45,82	9	6,25
03.08.2009	1	INJECTIE	M03-ENGEL 350T	79,76	78,86	94,92	92,61	69,32	55,29	69,32	78,86		149	149	100,00	17	36,60	23,93	8,76	60,18	10	6,53
03.08.2009	1	INJECTIE	M04-ENGEL 420T	86,33	97,49	100,00	97,53	95,08	82,08	95,08	97,49		37	37	100,00	10	8,40	44,03	3,70	32,70	6	16,99
03.08.2009	1	INJECTIE	M05-ENGEL 420T	62,05	31,57	100,00	100,00	31,57	19,59	21,72	21,72		371	371	100,00	14	117,11	22,60	26,47	63,70	11	2,84
03.08.2009	1	INJECTIE	M06-ENGEL 420T	90,20	88,81	51,89	85,85	39,57	35,69	39,57	88,81		211	211	100,00	53	45,80	8,68	3,98	165,91	159	75,57
03.08.2009	1	INJECTIE	M07-ENGEL 600T	89,43	92,08	73,51	85,09	57,60	51,51	57,60	92,08		135	135	100,00	28	29,53	16,29	4,81	88,40	95	70,30
03.08.2009	1	INJECTIE	M08-ENGEL 1000T	87,26	58,63	90,94	93,15	49,66	43,33	49,66	58,63		220	220	100,00	16	49,54	27,81	13,78	51,77	21	9,70
03.08.2009	1	INJECTIE	M09-NB 300T	88,61	99,06	85,94	96,95	82,53	73,12	82,53	99,06		17	17	100,00	7	3,77	64,56	2,43	22,31	5	27,52
03.08.2009	1	INJECTIE	M10-ENGEL 500T	87,99	100,00	8,93	100,00	8,93	7,86	8,93	100,00		14	14	100,00	4	3,12	112,19	3,50	12,84	3	19,55
03.08.2009	1	INJECTIE	M11-ENGEL 500T	85,36	93,06	87,13	97,17	78,79	67,25	78,79	93,06		73	73	100,00	11	16,79	39,58	6,65	36,38	18	24,97
03.08.2009	1	INJECTIE	M12-ENGEL 500T	85,25	87,05	72,75	100,00	63,33	53,98	63,33	87,05		111	111	100,00	14	25,62	31,05	7,95	46,37	30	26,79

Fig. 6. Parameters of the maintenance line

A computerized system monitors the work on line and displays the values of OEE for each workstation in real time. Integrating our method in the informational system gives the possibility to control the assignment of the tasks on the workstation and to increase the values of the OEE to 100% which is the maximal performance of the equipment.

Values of different OEEs are shown in figure 7. They are displayed in the same time on the computer and on the monitoring panels from the section walls.

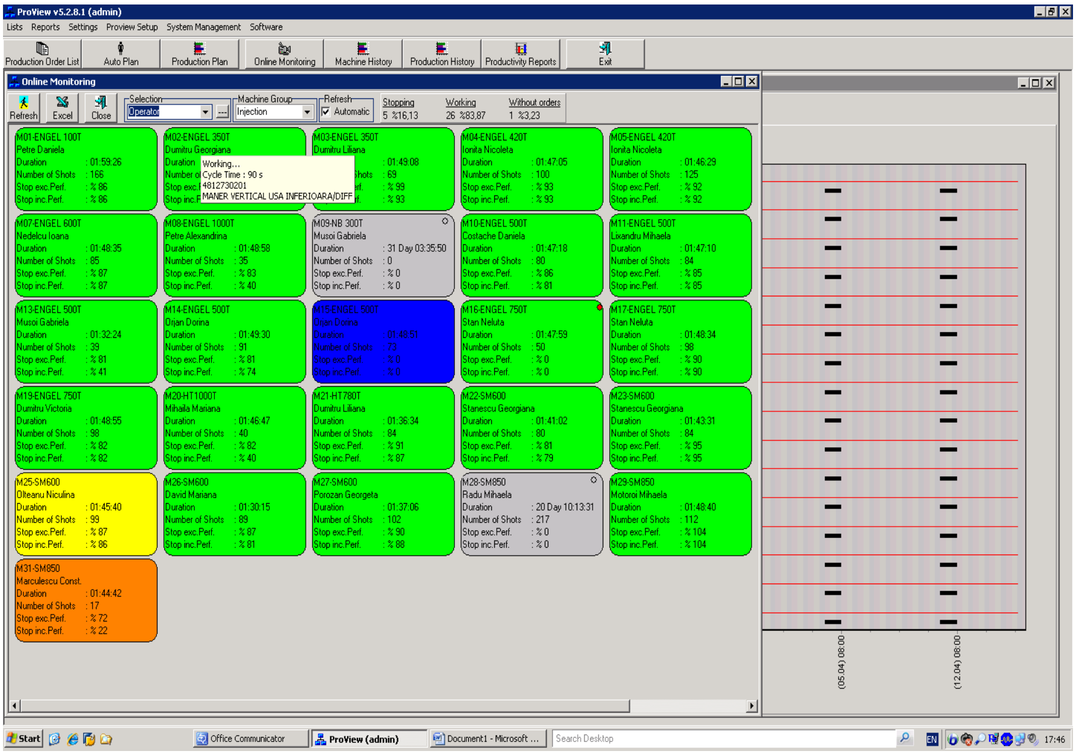


Fig 7 OEE values after optimization

A mathematical model is proposed in **(Pascale, Duta et al, 2012)** to assist the decision maker in the process of improving the overall performance of the manufacturing line. In fact, after accomplishing the optimal assignment of the tasks on machines, the overall performances in the terms of OEE and maintenance increased as it is shown in tables 1 a and b.

The method is based on the line balancing technique after minimizing the real cycle time using a linear programming model. The originality of the approach is the presence of decision variables in the objective function as well as in model constraints. After performing simulations on the mathematical model, TPM indicators values are significantly improved.

Availability	Performance	Quality	OEE
19,37	69,22	100,00	13,41
80,72	86,43	92,92	64,82
78,86	74,92	92,61	54,71
97,49	90,00	97,53	85,57
31,57	65,00	100,00	20,52

Availability	Performance	Quality	OEE
86,84	88,37	100,00	76,74
80,55	83,72	92,92	62,66
77,14	81,39	92,61	58,14
100	95,44	97,53	93,08
92,5	93	100,00	86,03

Table 1 TPM Indicators

a) before

b) after optimization

In **(Duta, 2012)** an intelligent decision tool aims to deal with uncertainties occurred in maintenance of a production line. After analyzing the corrective maintenance data, a decision model that integrates the most important maintenance indicators and their probability distributions is provided. The tool used for modelling and simulation is the Bayesian Network. To capture the temporal evolution of modeled system Dynamic Bayesian Networks are used. These networks introduce relevant temporal dependencies that capture the dynamic behaviors of the system at different moments. A case study of the maintenance ensured on a line served by four fixed workstations and a mobile shuttle has been carried -out. Four steps are covered during the process analysis: identifying the critical machines via a cross-analysis of maintenance indicators; developing a model and a priority ranking according to the previous analysis; simulation of machines behavior; proposing action plans through maintenance procedure. Forward, a probabilistic graphical model for decision aid in preventive maintenance strategies is conceived (figure 8).

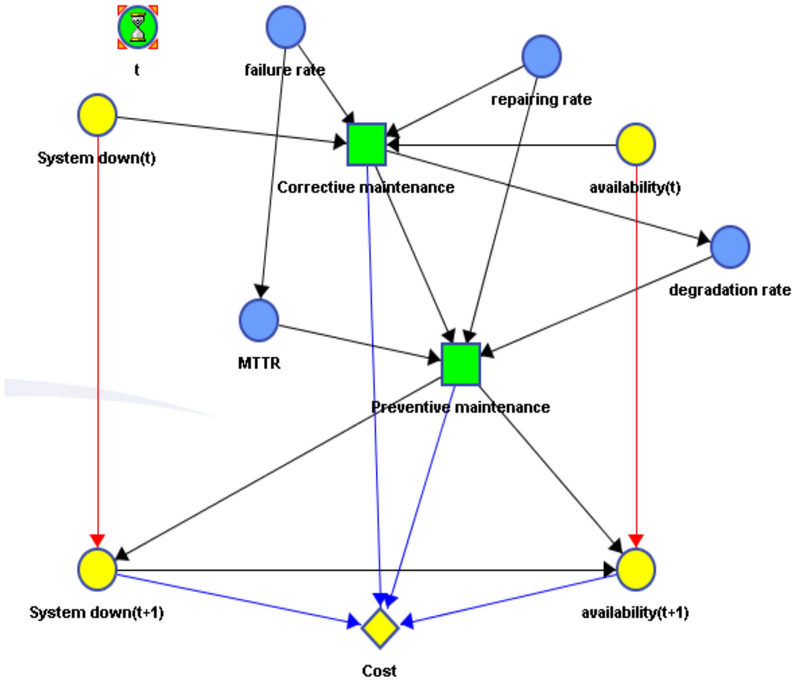


Fig. 8. Dynamic Bayesian Network model

Performing the analysis on the corrective maintenance data base, a probabilistic model for aid in decision-making in preventive maintenance has been developed. The analyzed indicators were availability, maintainability and maintenance costs. This work[4] gave a solution for developing probabilistic models in decision aid for preventive maintenance strategies starting from the corrective maintenance data.

The purchasing policy of spare parts for maintenance is reviewed in **(Ghorbel, et al., 2011 b)**. In this paper, a decision tool for sustainable inventory control is proposed. The tool was also conceived with the help of Bayesian Networks. In spare parts (SP) inventory control the aim is to maintain the inventory at an optimal level and to minimize the purchasing and the inventory costs. This paper deals with integration of the recycled spare parts in the economic models of inventory systems.

In literature there are four inventory basic policies for replenishing inventory (Blumenfeld D., 2009):

[4] The paper won a prize being published in a revue from the yellow zone of AIS list

- *(s, Q) Policy:* Whenever the inventory position (items on hand plus items on order) drops to a given level, s, or below, an order is placed for a fixed quantity, Q.
- *(s, S) Policy:* Whenever the inventory position (items on hand plus items on order) drops to a given level s, or below, an order is placed for a sufficient quantity to bring the inventory position up to a given level, S.
- *(T, S) Policy:* Inventory position (items on hand plus items on order) is reviewed at regular instants spaced at time intervals of length T. At each review, an order is placed for a sufficient quantity to bring the inventory position up to a given level, S.
- *(T, s, S) Policy:* Inventory position (items on hand plus items on order) is reviewed at regular instants spaced at time intervals of length T. At each review, if the inventory position is at level s or below, an order is placed for a sufficient quantity to bring the inventory position up to a given level S. If the inventory position is above s, no order is placed.

The indicators Q, s, S, and T are defined as follows:

Q = order quantity

S = order-up-to level

s = reorder point

T = review period

Since the demand for spare parts is variable and dependent of the maintenance needs, we placed our work in the (T, s, S) policy case. In such case, the period of review is fixed and ordered quantity changes as per demand or rate of consumption.

In real maintenance systems the demand of spare parts is variable due to the changes in the production volume, rate of machine failures and workers availability. In the same time, the inventory volume cannot be set for a planning period, due to the delivery delays or lead times in delivery.

A common characteristic of dynamic inventory models with stochastic demand is the assumption that the demand and the costs distributions are known with certainty. In real systems these are parameters with a level of uncertainty provided by the dynamics of the production and market environment

The results obtained in this work incorporate the dynamic approach into the spare parts inventory management by using the Bayesian formalism so as to update the costs and the demand at each moment. In the same time, we are looking to combine the dynamic inventory with Bayesian Network learning so as to obtain a dynamic model close to the real system. To accomplish this aim one has to use the Dynamic Bayesian Networks, a well suited modeling instrument for complex systems submitted to uncertainties.

The Dynamic Bayesian Network is presented in figure 9.

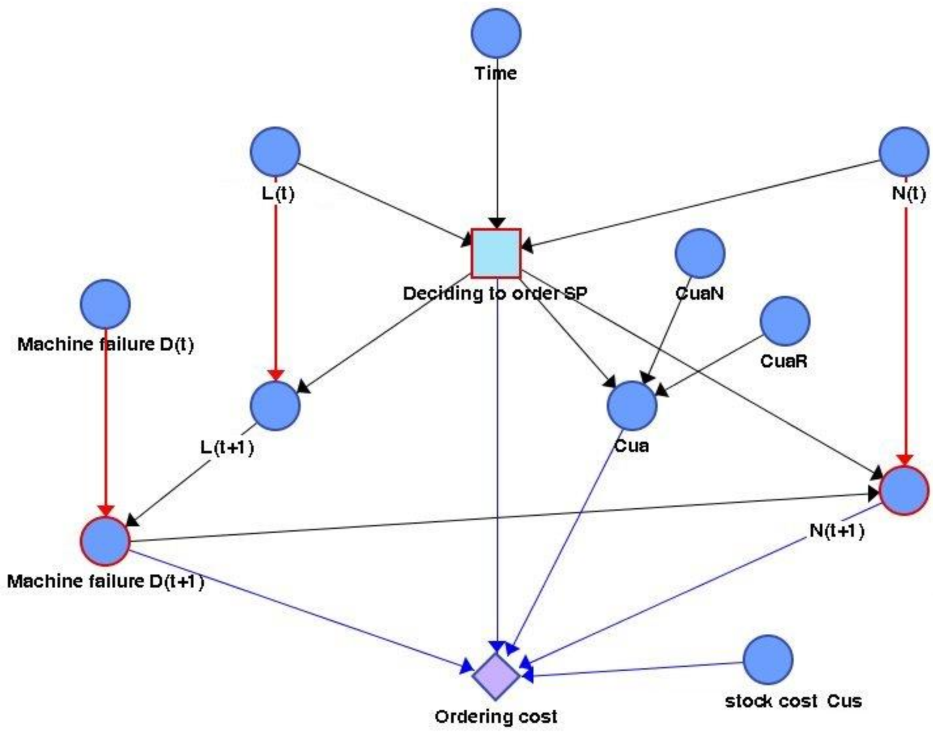


Fig 9. DBN for spare parts inventory control

Taking into consideration all the uncertain parameters and their probabilities a DBN that represents our problem was structured using Bayesia Lab® software. Launching the simulation one could observe the learning process of the DBN. The missing data is dynamically completed and the joint probabilities are updated at each step.

The final results are interesting. At the beginning of the period, there is a need of spare parts purchasing since the demand is high and the stock is decreasing rapidly towards the security level. Beginning with the 11th day of the month, there is a need of new spare parts so the order must be lunched before this date.

And at the end of the month, purchasing variable quantities of recycled spare parts could minimize our costs. One could observe that even we start from the (T, s, S) policy, the order is given at variable periods (figure 10).

At it is shown, a Bayesian Network is a useful tool in decision aid and real time optimization, since it learns how to behave itself according to the input parameters which are variable.

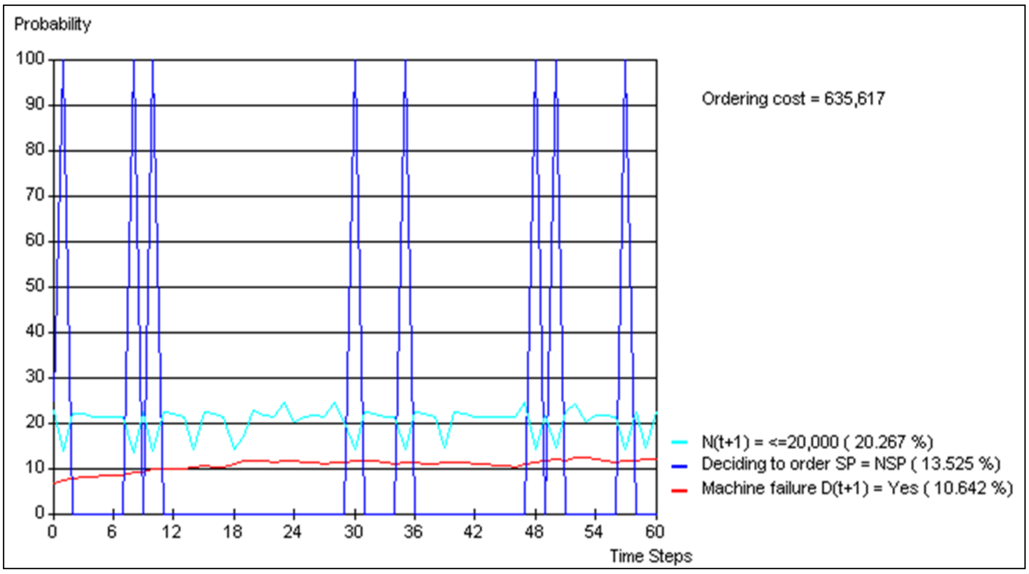


Fig. 10 Order variation over the planning period

4.1.3. Collaborative Decision Making Tools

Decision Support Systems (DSS) form a specific class of computerized information systems that support business and organizational decision-making activities. In manufacturing, DSS provide the effective support of the management necessary in decision making processes. Manufacturing Decision Support Systems (MDSS) refer to the latest developments in computer aided design, computer aided manufacturing, manufacturing simulation, control of flexible manufacturing systems, computer integrated manufacturing, intelligent machining, intelligent manufacturing systems etc.

Collaboration in the frame of these systems implies consultation of different decision makers and deployment of a group decision methodology and support. Collaboration is now developing on integrated business platforms that must provide the seamless flows of information across organizational and departmental domains, regardless of which technologies or standards are in place.

In **(Patic, Duta et al)** a collaborative environment for practice in virtual enterprises in which actors are students, universities and real companies is presented. A Simulated Enterprise (SE) is a virtual company that simulates the structure, the functions and the operations of a real company, but without real money exchanging. A SE is in the same time a training ground for entrepreneurial thinking and action.

The collaborative platform architecture is a service orientated one. It includes an ERP solution to interconnect the simulated enterprise departments, a collaborative customer relationship management module (CRM), an open source web-based learning management system (ILIAS), a database management system, a group decision aid tool, and a GPS map of all national existing simulated enterprises (Fig. 11). Data bases include information about all participants of the collaborative environment and their relationships: students, teachers, faculties, universities, managers and experts from real companies, simulated enterprises managers, etc.

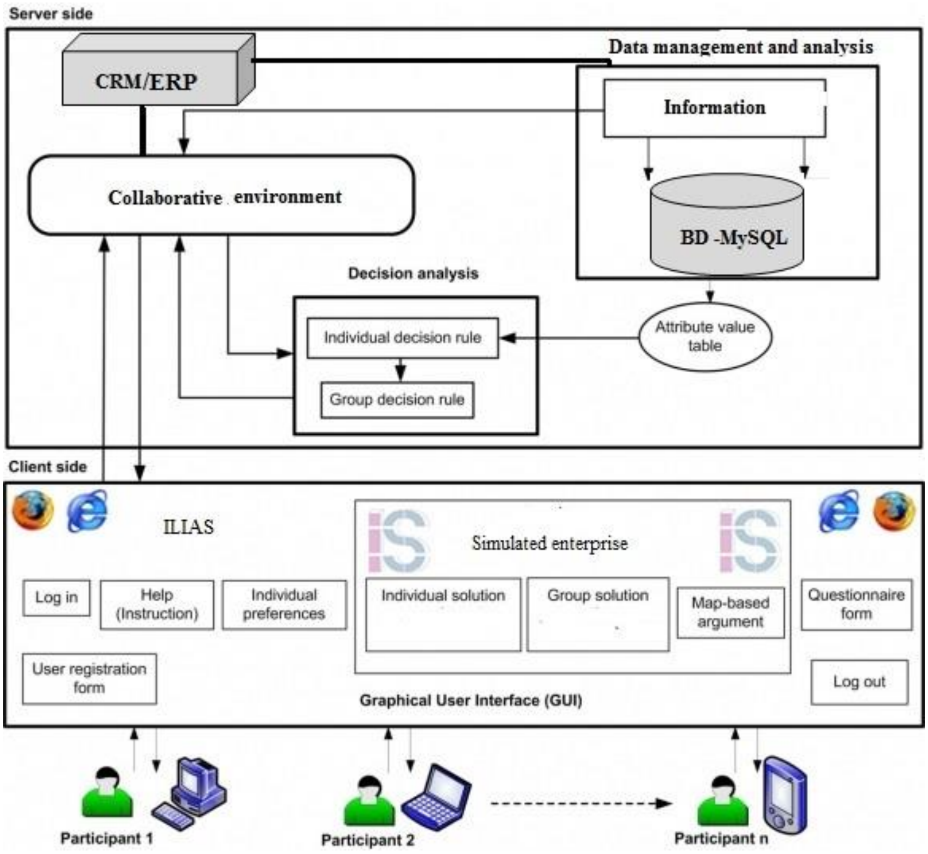


Fig. 11 Collaborative decision platform architecture

Small and medium-size enterprises need to integrate their processes, services and relationships with customers and suppliers, in a cost-effective manner, given the fact that ERP systems are quite expensive for such organizations. That's why in **(Cioca et al, 2011),** in order to select the best modeling language recommended for the EMLs (Enterprise Modeling Languages) block of the GERAM architecture, we have analyzed some modeling languages as GRAI/GIM, Petri networks, OOA/OMT, CIMOSA, IDEF0, IDEF1X, IDEF3, IEM, ARIS, EXPRESS and UML. Criteria taken into account were the methodological support, the CASE tools, the information and the resource perspective, the functional decomposition, the genericity. The conclusion of the multicriteria analysis is that the UML is the recommended language for the internal enterprise modeling, but for integration with suppliers and customers, Web technologies should be used.

Zamfirescu, Duta and Candea (2010 a) investigate the possibility to externalize and support, from a metacognitive perspective, the effective use of facilitation knowledge with self-development capabilities. The experimental results make evident that these capabilities may be easily engineered by adopting the basic principles of the design for emergence in constructing an e-meeting facilitation tool that act as a stigmergic collaborative environment for the participants. Any stigmergic system has two main components: the population of agents and the shared environment through which they are interacting and coordinating their behavior. The cognitive complexity for the Group Decision Process (GDP) design is given by the thinkLet (TL) concept that has been introduced to define the smallest piece of essential facilitation knowledge of group decisions. The emergent behavior of designing the GDP resides in identifying relevant TLs which maximize the GDPs performance for a problem type.

In **(Zamfirescu et al., 2010 b)** authors investigate the cognitive complexity associated with the design of group decision processes (GDP) in relation with some basic contextual factors such us task complexity, users' creativity and problem space complexity. The analysis is done by conducting a socio-simulation experiment for an envisioned software tool that acts as collaborative environment for the GDP design. The results show that the dominant factor for the wide adoption of GDSS technology in real organizations still remains the problem complexity.

A similar approach is described in **(Zamfirescu et al., 2012).** Here authors investigate the power of stigmergic coordination mechanisms (SCM) to deal with the inherent uncertainty in planning the group decision process (GDP). The investigation is made using a socio-simulation experiment that captures the users' behavior in planning the e-meetings' agenda as supported by a Group Decision Support System (GDSS). To evaluate the planning strategies for modelling the GDP, the model described in the previous section has been implemented in the Netlogo multi-agent simulation environment. In this experiment the users are engaged in planning the e-meetings' agenda and defining the GDP model for a problem type by moving in the conceptual graph of the problem space. From the swarming models of computation uncertainty acts as a stimulating driving force to increase the number of planning decisions by raising the representation complexity for a GDP through the possibility to structure it in terms of high-level cognitive plans or sub-plans.

An experimental decision aid Web-based system for a financial database is presented in **(Bobosatu and Duta, 2010).** The model of Web Based Decision Support System is intended to assist financial managers to choose the best solution, in the decision process of buying shares from the analyzed companies. Through the Web interface the proposed system can present graphical information to a multitude of users and it can be easily integrated with an expert system or artificial intelligence system. The experimental Web-Based Decision Support System is installed on the decision machine. It is composed out of the following main components: a SQL server 2008 database, an Analysis Server 2008 database and Web Applications.

An interface for an ideal Web based group decision support system is described in **(Suduc et al, 2009)**. The role of facilitator and members of the group are distinguish presented. The activities of each are presented in a Use case diagram (figure 12). The interface for the facilitator must be richer than for the individual decision maker since it must give access to four main activities: brainstorming, ideas organizing, prioritizing and policy developing.

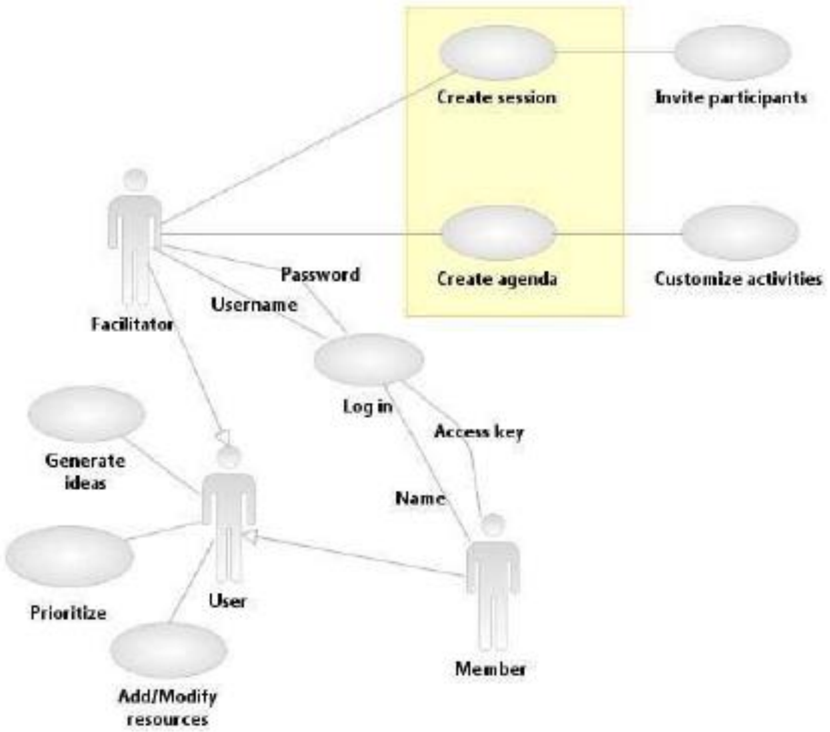


Fig 12 The Use Case diagram for GDSS

Other class of Group Decision Support Systems was investigated for transportation applications. In **(Duta et al 2009 b),** authors proposed a DSS to compute the optimal transportation capacity and flow on a certain railroad from Romania. To support the decision analysis concerning the investment for supplying the railroad capacity on the trans-Carpathian lines, Precision Tree® a software product of Palisade was utilized. The decision maker has to choose between three decisional alternatives, investing in one of the three transportation corridors. The results show that the proposed software is suitable for simple decision problems and taking into account the economic criterion.

Another application in public transportation is exemplified in **(Duta et al, 2010)** where DSS facilities were integrated in an information system delivered by a Swedish company (Thoreb). The vehicle computer provides driver guidance along the route on a map on the left display. The map is automatically rotating to always display the actual driving direction as straight ahead. The right display (Thoreb T-video) displays one or up to four camera images. Which camera image to display can be automatically controlled by the system based on signals from the multiplex electrical system, e.g. rear-view image is displayed when the reverse gear is active, and the internal and external door camera images are displayed when the doors are open. The authors developed a method to import/export data via web on local files for analyzing data. The software used to interact with Thoreb system is Vanguard Decision Pro. DecisionPro is a powerful application for decision-support analysis and business modeling. DecisionPro combines all of the basic quantitative methods in management with features of spreadsheets, artificial intelligence tools, and math applications to produce an advanced business modeling system. The decision maker can generate reports and make sensitivity or risk analysis on the base of imported information. Reports can be created and printed in .doc, .xls or .pdf formats.

In **(Istudor et al, 2010)** a GDSS for evaluating the enterprise performances is proposed. In an economical and financial sense, to obtain performance means to achieve economic profitability and economic growth. This performance indicator gives information about economic profitability and treasury cash flows generated by the exploitation of enterprise's resources. The web-based GDSS allows decision makers to apply this method to their own set of data so as to take a good decision in respect of the indebted degree of their enterprise.

In **(Tchoffa et al, 2013)** a method for information system incidents management is proposed. The approach is based on a complete decision analysis using DPL® software. The monitored incidents occur in information systems. Influences and causalities between hardware and software incidents and defects are studied.

4.2. Optimization of Remanufacturing

In recent years, processing of end of life (EOL) products in a responsible manner, maximizing parts/material new usages and minimizing the disposal become both economically and ethically imperative. It is part of the efforts made for sustainable manufacturing systems (Wang and Gupta, 2011) (Seok, et al. 2012). Lot of researchers concentrates attention upon the **three-R options** for an EOL product: *repair-reuse, recycling* and *remanufacturing*, trying to find methods to make them efficient. Remanufacturing must not be confused with other related processes as reusing, reconditioning or recycling. A reused product retains the technical problems acquired on its previous life, even if it is still functional. Reconditioning restores the functionalities of the used product but there is no warranty matching to the original product. Moreover, repairing and reconditioning are processes that do not necessarily imply the complete disassembly of the whole product. Recycling process transforms the product ore a part to raw material, which can be used for a future manufacturing process.

Remanufacturing views “waste” as a resource. It is recapturing the material value added when the product was first manufactured and it brings resources into reuse preserving the quality of the natural environment. From the economic point of view, remanufacturing is more profitable than manufacturing, since it requires less labor, energy, materials and disposal costs. In the same time, remanufacturing allow consumers to acquire good quality products at low prices (Ilgin and Gupta 2012).

The remanufacturing process is composed by eight distinct phases: collection, inspection, faults identification, disassembly of the whole product, parts cleaning, parts reconditioning, product reassembly and testing (Sundin 2004).

Disassembly is a process in which a product is separated into its components and/or subassemblies by nondestructive or semi-destructive operations. Within the realm of sustainability in manufacturing, disassembly is applied on end-of-life products to valorize materials or components. Disassembly may also be considered as a source of refurbishing components for remanufacturing process, aspect that influences the product strategy design. Remanufacturing by reuse of parts provided by EOL disassembly is a technique used in remanufacturing of geothermal pipes, automotive engines, railways trains, aircraft and data communication equipment, robots or musical instruments (Gray and Charter 2007).

In the disassembly process, the product can be *completely* or *partially* disassembled. A complete disassembly is performed when the product is subjected to the process of remanufacturing or recuperation of parts and materials. A partial disassembly of the product is performed when three EOL options are envisaged: reusing, recycling and disposal (figure 13).

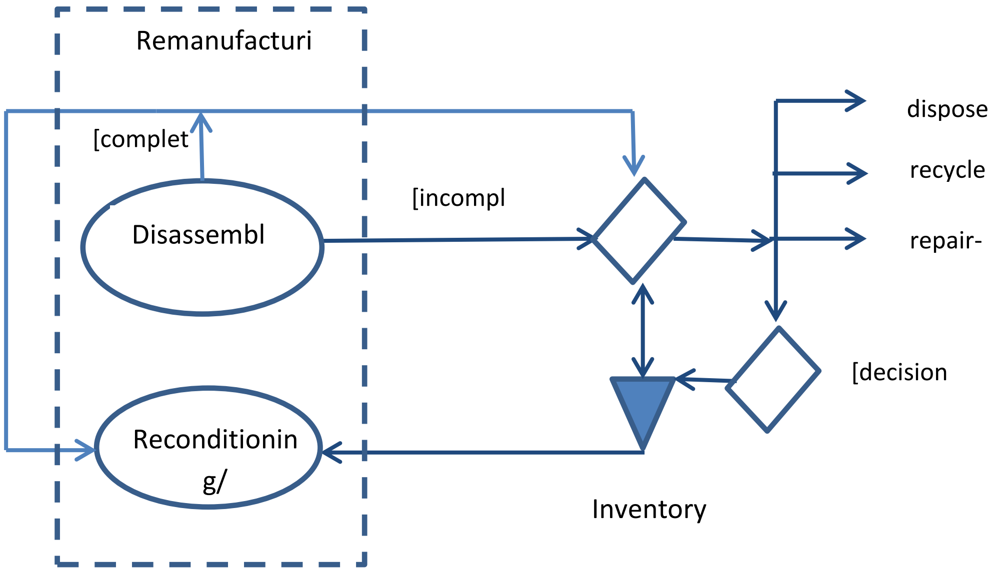


Fig 13. EOL options after disassembly

This chapter research is structured in three parts:

4.2.1. Disassembly planning

4.2.2. Disassembly scheduling

4.2.3. Disassembly balancing

4.2.1. Disassembly planning

Planning of the end-of-life phase of products is becoming more and more important for manufacturers because of environmental regulations and economic reasons. Intelligent valorization of end-of-life products became necessary.

The objective of disassembly planning is to identify the sequence of disassembly operations that will maximize the expected returns from the processed items. A basic problem of disassembly is the sporadic number of similar units and the broad variety of product types.

This requests a very high flexibility of disassembly technology that can be mostly realized only by expensive manual work. As a result, a reasonable trade-of between economic and environmental benefit, that determines the disassembly depth, should be made. Moreover, disassembly research works are related to end-of-life valorization methods which are based, mainly, on the research of the most gainful disassembly sequences for considered products.

Most often, it starts from product model that provide feasible operations. These operations are used to build generally AND/OR disassembly graph representing feasible decomposition of a product into its elementary components and subassemblies. Usually a cost is given for each disassembly operation according to the kind of attachment involved. The cost-benefit analysis gives penalty for each unwanted component that must be extracted in order to recover selected component. The total evaluation is then defined as the ratio between gain and cost.

Disassembly to order (DTO) is the determination of the optimal lot sizes of EOL products to disassemble in order to satisfy the demand of various reusable components or subassemblies. In a DTO system, the demand for remanufactured products triggers the disassembly of EOL products (McGovern and Gupta 2011). A DTO system is concerned with the process of finding how many products have to be disassembled in order to fulfill the demand of reusable parts or subassemblies that will be used in remanufacturing. Complications related to the unknown quantity and quality of parts obtained from the EOL products lead to disassembly yields under uncertainty. Another problem is to coordinate disassembly and remanufacturing processes so as to meet the demand of new items. The disassembly depth that deals how completely a product should be disassembled is another complication. In this context, the researcher must weigh not only the costs of the process, weather is destructive or not, but also consider which reusable parts are already in stock, how many will be obtained through disassembly and will be accumulated in inventory and how many parts will have to be disposed of (Lambert and Gupta 2005). Therefore, the disassembly planning strategy is a multi-objective decision making process, taking into account the different possible EOL options (Kou and al. 2012). The aim of present study is to develop a decisional model to help industry people in finding the best strategy to disassemble a number of products so as to meet the demand of components necessary in remanufacturing. This issue is related to the theory of disassembly inventory.

In **(Duta and Patic, 2007)** a review of existing automatic disassembly cells architectures is made. At that time, few implementations of this kind of cells were functional in remanufacturing processes. Sony DADC Austria was one of the largest producers of optical storage units – Mini Discs as their main product.

As it is typical for every industrial production, some of the produced Mini Discs do not satisfy the desired high quality standard. Due to the rising waste disposal costs and the high costs of human work, an automatic recycling of Mini Discs was the key aspect of this project. At the Institute for Handling Devices and Robotics from the University of Vienna a disassembly cell for printed circuit boards was conceived. The layout of the cell is shown in Figure 14. The basis of a disassembly cell is a very stiff frame construction developed from commercially available profiles. The disassembly cell consists of four stations: vision system, laser dismantling system, removal station, heating removal station. The vision system has several tasks. It has to recognize the re-useable parts by means of a data base containing the data (company, dimensions). The vision system has to detect the re-useable parts and to determine the position, the size and the center of inertia. Furthermore it has to classify the parts to be dismantled or removed from sockets. The dismantling station consists of a cross table –two linear axes – controlled to reach every point (center of inertia) on the printed circuit boards (Kopacek and Kopacek, 2005).

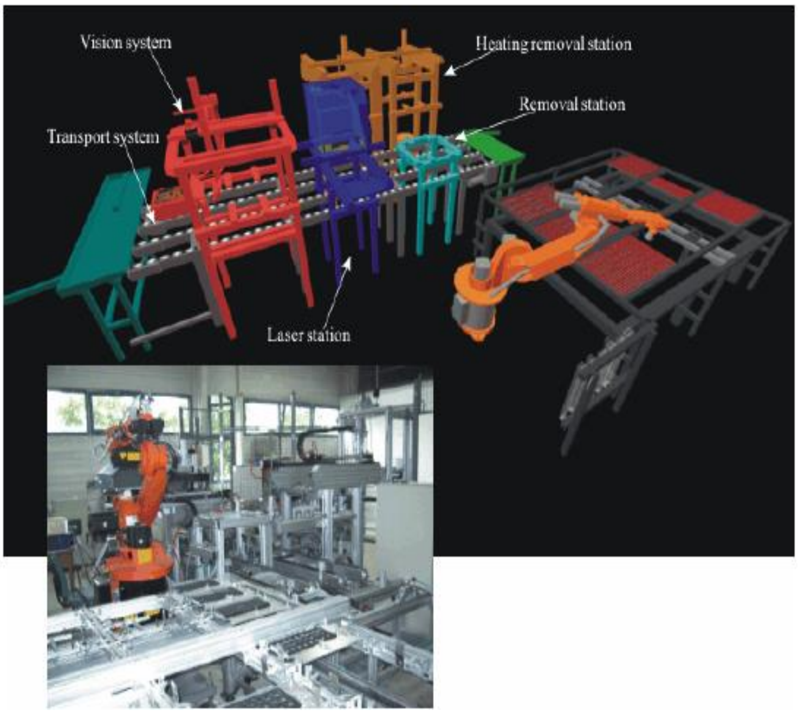


Fig. 14 Disassembly cell for PCB

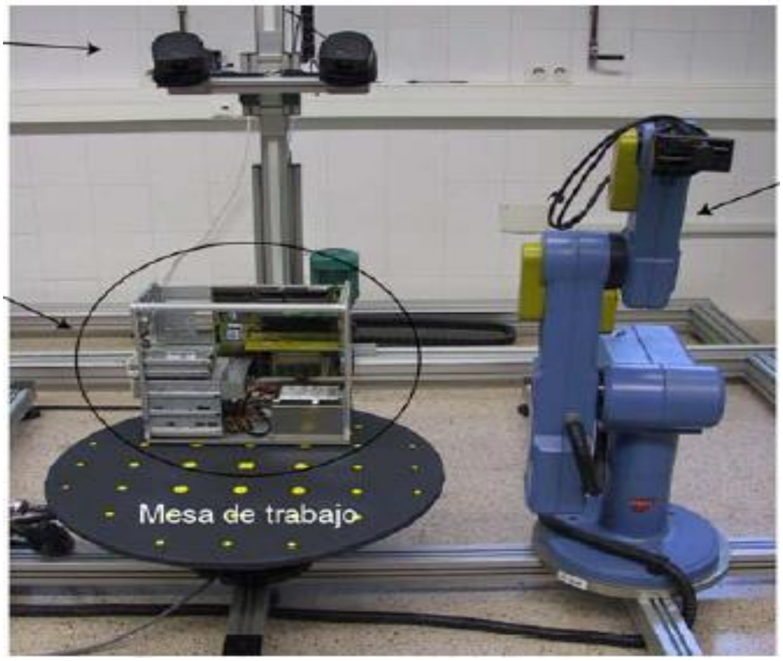


Fig 15 Disassembly cell for PC

In (Puente, 2002) the author used the relational model to represent the links between the components of a personal computer. The architecture of the disassembly cell contains a Scorobot ER-IX robot with five liberty degrees, a moving table where the computer is fixed, and an artificial vision system fixed on a Cartesian y-z robot that tries to localize the components of the product (Fig 15).

In **(Addouche and Duta, 2008)** a disassembly planning case study of an automotive product at end-of-life phase is presented. The method proposed in this paper is based on linear programming model but founded around Petri Net disassembly representation. This combination enabled us to obtain, in a systematic way, the most advantageous disassembly plans. And this is dependently of disassembly costs and incomes of constituents recycling of the end of life product. This method has been developed into two stages. First, all feasible and pertinent disassembly plans were generated and the most profitable ones were selected in the second stage. All resulting plans are given in a single Petri net form that is called “Disassembly Petri Net” (DPN) and contains the different possibilities to disassemble product. Places and transitions correspond, respectively, to the elementary components or subassemblies and disassembly actions involved in a product disassembly. The method was implemented for the disassembly of a car dashboard (Figure 16)

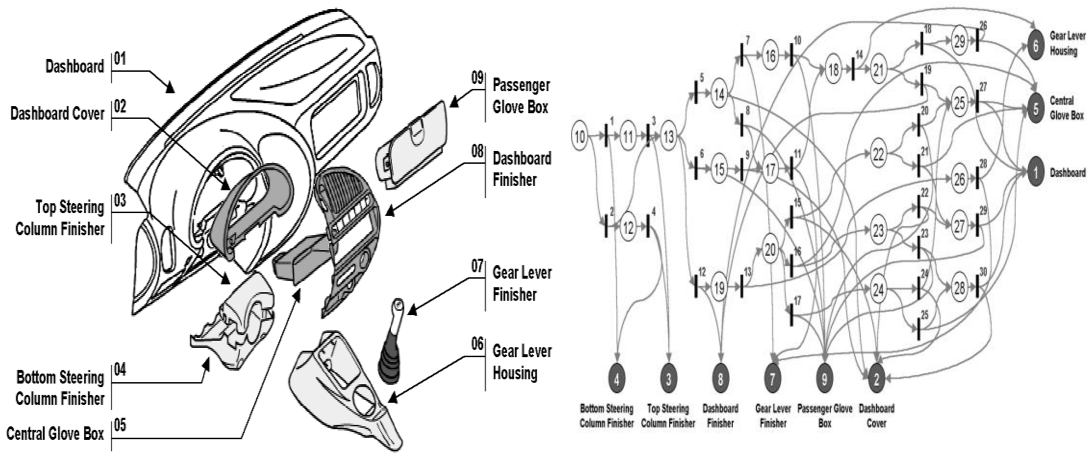


Fig.16 Disassembly of the car dashboard

In this case the results show that an incomplete disassembly is preferred to a destructive one. There are five components and two subassemblies recovered figure 17. The proposed method gives the most profitable disassembly sequence for a given product and allows, in the meantime, a complete analysis of the whole set of disassembly sequences in respect of obtained costs and incomes.

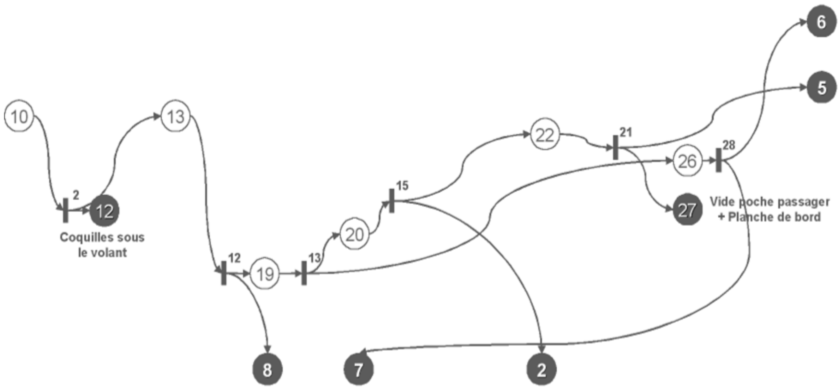


Fig 17 Optimal disassembly sequence of the dashboard

Addouche, Duta et al. (2009) develop a predictive model to make into account continually the defective conditions of all components of EOL product in order to determine the most profitable disassembly depth. The decision-making model uses linear programming formalism to perform most profitable disassembly plan and entropy analysis to increase the chances to select the successful of disassembly operation. The approach is demonstrated by a case study of EOL vehicle. An entropic (causal) analysis was run on the model and an influence histogram representing influence indicators was obtained (figure 18).

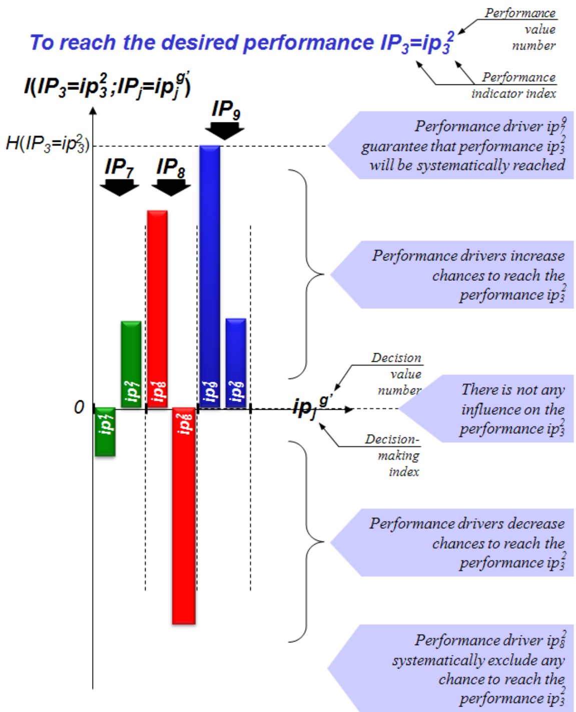


Fig. 18 Driver set influence histogram for a given performance indicator

A different perspective of disassembly planning is presented in **(Ghorbel et al 2011, a)**. The problem of replacing new spare parts with recycled spare parts was addressed so as to minimize the inventory costs. The recycled spare parts integration problem in economic models of inventory control is studied. In order to facilitate the inventory control of spare parts, the authors propose a probabilistic model formalized by a Bayesian network. The model is used to identify the best purchase policy. More precisely, it allows choosing the best proportions between new spare parts and recycled spare parts by taking into account the traditional criteria of inventory control and the availability of the spare parts on the market. The proposed method provides a decision-making tool for manufacturers who are interested both in reducing the costs of stocks and guaranteeing a minimal availability in an uncertain environment.

Bayesian Networks, as decision tools, are used again in **(Duta and Addouche, 2012).** A method to find influences and causalities between the main disassembly performance indicators in order to decide the optimal disassembly policy is proposed in this work. The model highlights the temporal dependencies be-tween variables of the system and is validated using the Bayesian Lab software. A Bayesian Network (BN) is an appropriate graphical method for modeling of causal processes and probability-based knowledge representation under uncertainty. A BN is a directed acyclic graph whose nodes represent random variables and links define probabilistic dependences between variables. Bayesian networks have the ability of capturing both qualitative knowledge through their network structure, and quantitative knowledge through their parameters. A static Bayesian network can be extended to a Dynamic Bayesian Network (DBN) model by introducing relevant temporal dependencies that capture the dynamic behaviors of the system at different times (Murphy, 2002). Simulation was applied to a disassembly of a notebook. In the learning process, the DBN uses an algorithm to complete dynamically the missing data and the joint probabilities are updated at each iteration execution. The end of life options, costs and revenues influence the type of disassembly operation so as the decision is taken dynamically considering the state of the component. As the result of real time decision making, disassembly operations are fulfilled in 45% of cases, the rest of 65% being destructive operations. The BN and the results of simulation are represented in figure 19 and 20.

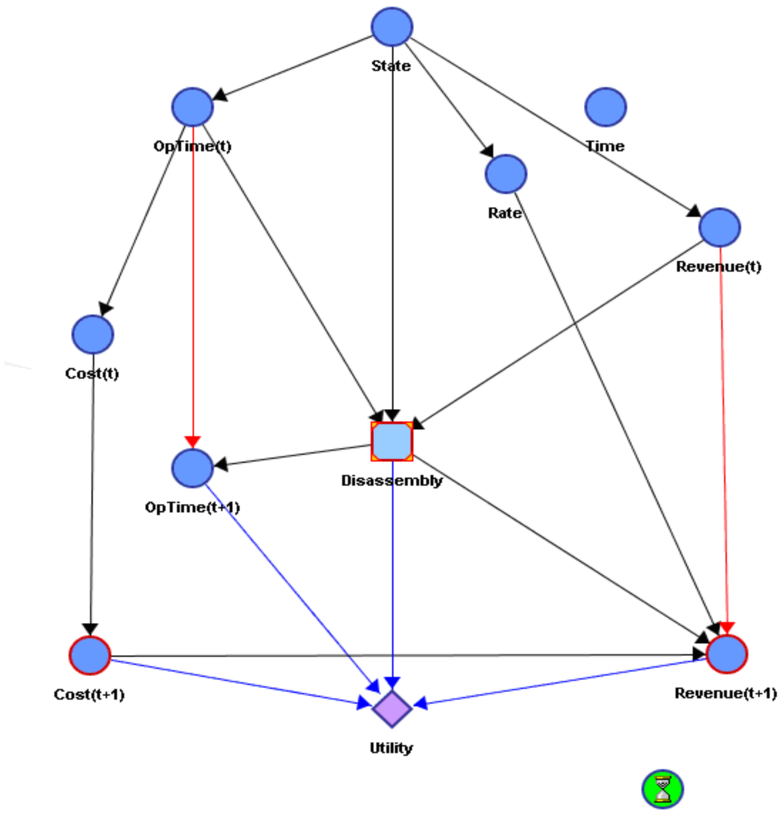


Fig. 19 Disassembly BN

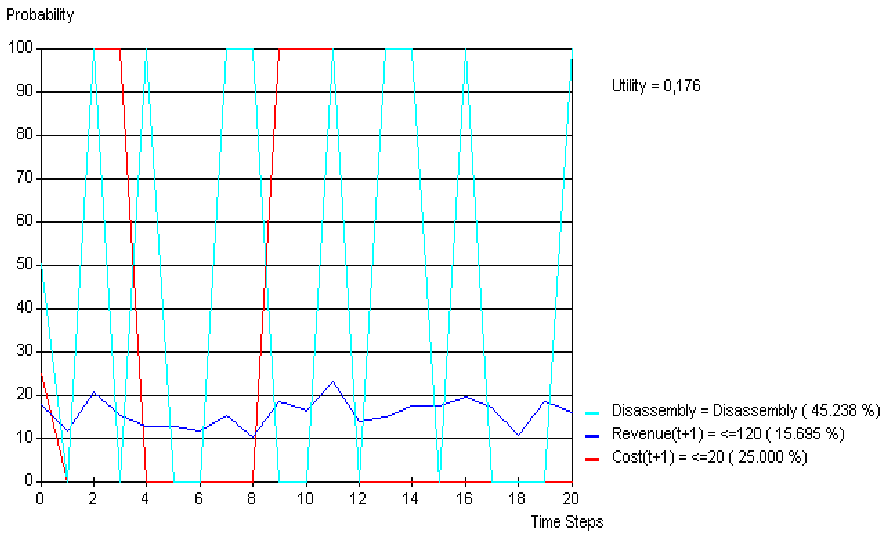


Fig 20. DBN decision steps

In **(Duta and Filip, 2008)** authors the authors aim at surveying several state-of the art solutions of robotized disassembly cells and the associated control software. Here is presented the application conceived in Visual C++ during the PHD Thesis **(Duta, 2006)** for controlling the disassembly process of mobile phones The optimal disassembly sequence is obtained from the optimal disassembly tree and from the disassembly Petri Net (figures 21 and 22).

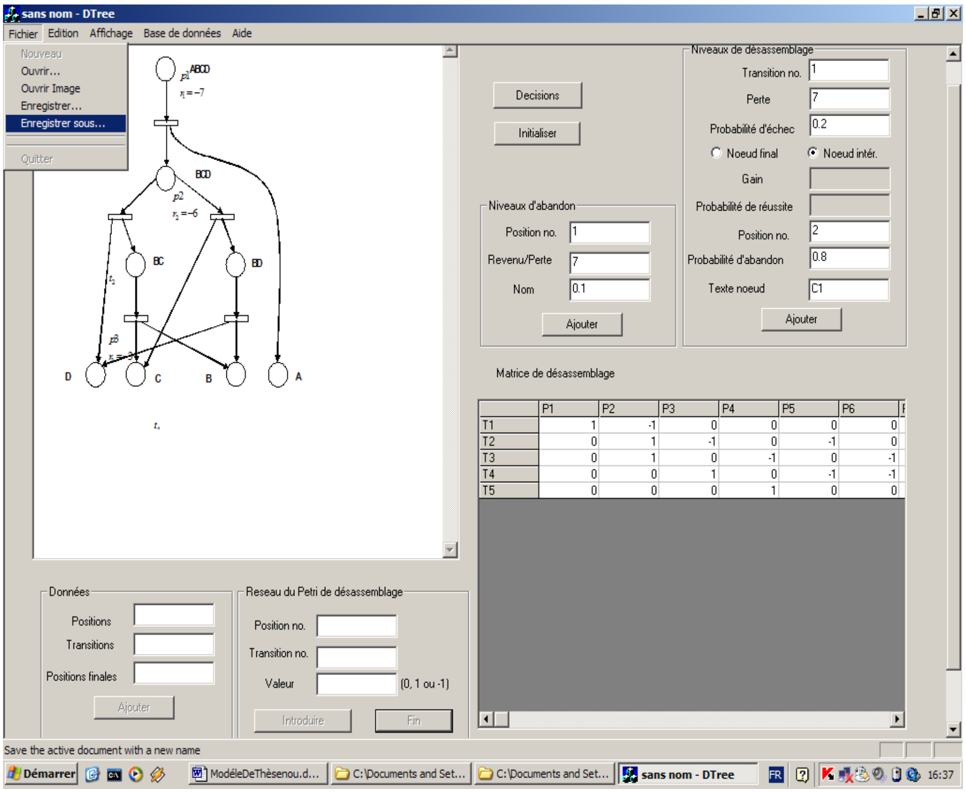


Fig 21. VC++ application for representing the DPN

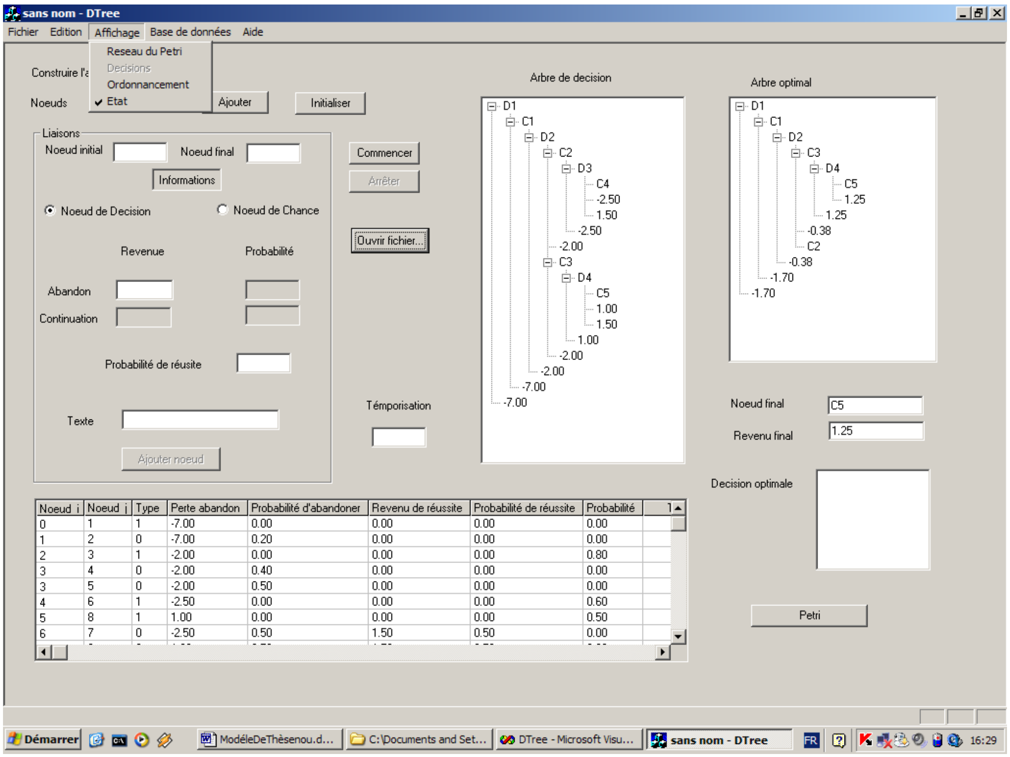


Fig 22. Generated decision tree

4.2.2. Disassembly scheduling

Another problem raised by the disassembly process is disassembly operations scheduling. *Disassembly scheduling* can be generally defined as the problem of determining the quantity and timing of the end-of-use/life products while satisfying the demand of their parts over a planning horizon (Kim, 2005). The objective is to minimize the processing time and the inventory costs and to maximize the final revenue. This problem is made more complex by the occurrence, during the disassembly process, of uncertainty in the possibility of components separations. Deteriorations and deformations of some elements, absence of one or more components, presence of corrosion and rust are perturbations often encountered in disassembly of EOL products. Therefore, some operations cannot be carried out due to the physical degradations of the components and other operations are not performed if they are not profitable. So, a choice has to be made, between applying an alternative disassembly destructive operation (dismantling), and abandoning the disassembly procedure. Scheduling problems are generally considered to be NP-complete and necessitate the use of heuristics or metaheuristics.

Control of disassembly process involves two essential decision variables: disassembly level and disassembly mode: clean or destructive. A third decision variable may be added: the task to station assignment. This decision variable, the only one available in assembly is far more constrained than the two former ones, that makes control of disassembly systems a far more complex problem than the control of assembly systems. This optimization problem depends upon the structure of the disassembly system: if it is made of a single workstation, the costs depend mainly upon the process duration. If the system is a line, the costs depend mainly upon the line balancing.

In this paragraph, a review of my work on disassembly line scheduling and balancing is presented.

In **(Duta and Addouche, 2007)** the authors consider that the line structure was given and propose an algorithm which will allow finding a disassembly sequence that optimizes a very simple function integrating the income from the parts and the cycle time of the disassembly line. A stochastic algorithm is used to fulfill this optimization.

The objective function to maximize is the revenue on time unity:

$$f = \frac{r}{t_{cy}} \qquad (1)$$

Where *r* is revenue associated to each disassembled part and *tcy* is the cycle time.

The final revenue is the sum of partial revenues obtained according to the end-of-life destinations of the disassembled parts. These partial revenues are established by experts after repeated disassembly processes.

$$r = \sum_i r_i \qquad i = 1..m \qquad (2)$$

Where *m* is the number of final components or subassemblies resulted at the end of the disassembly process and *ri* are the associated revenues. The cycle time *tcy* can be defined as the operational time of the slowest workstation on the line.

$$t_{cy} = \max_{W_i} \sum_{j \in (tasks\ on\ W_i)} t_j \qquad (3)$$

Where W_i is the workstation *i*, *j* is a disassembly operation and t_j is the operational time needed by the operation *j*.

The algorithm used for the maximisation of the function given in the previous section is a Kangaroo algorithm that belongs to the category of stochastic algorithms. The Kangaroo algorithm provides a solution using a stochastic descent and a transition in the neighborhood to find a better solution of the current one. This stochastic method guarantees a local optimum in an acceptable time. Applied on a radio and a car dashboard disassembly, the results show that the algorithm gives the most profitable disassembly sequence for a given product and allows, in the meantime, a complete analysis of the whole set of disassembly sequences in respect of obtained costs and incomes. Applying a stochastic algorithm the quantity of data decreases and the calculus speed rises. In the disassembly process a local and quick solution for the optimal disassembly sequence is preferred to the complex and slower algorithms.

The same optimization problem was treated in **(Duta et al, 2008 a)** but using another tool: *the genetic algorithms*. A chromosome is represented by the possible tasks assignment matrix:

$$s_{ij} = \begin{cases} 1 & \text{if the task j can be assigned to the worstation i} \\ 0 & \text{if the task j can't be assigned to the worstation i} \end{cases} \quad (4)$$

Where $i = \overline{1..n}$ and $j = \overline{1..m}$ (*n* is the number of workstations and *m* – the number of disassembly operations)

Initial population is formed by all possible assignment matrices. Selection, crossover and mutation were applied on this population. Running the algorithm on an example, results show that the performances and fitness of new generated population (assignment matrices) grow, so that the optimal tasks assignment on workstations was obtained. The algorithm does not optimize the balance of the disassembly line, but give a solution that improves this balance.

4.2.3. Disassembly balancing

Disassembly operations are associated with high degree of uncertainty which results in the unpredictability of the system. One way to deal with this problem is to find the most feasible disassembly sequence and another is to insure the balancing of the line. First researchers who address the problem of disassembly line balancing were (Gungor and Gupta, 2002). In this paper, authors defined the disassembly line balancing procedure (DLBP) as the minimization of the number of workstations while minimizing the idle times between them and fulfilling all constraints. Since the DLBP is a NP-hard problem, in recent years many studies were dedicated to this problem. Classical algorithms as branch and bound, greedy, backtracking and heuristics or metaheuristics (ants' colony, bees' colony, and genetic algorithms) were used to obtain the balance of the disassembly line. A literature review on disassembly line balancing is done in (McGovern and Gupta, 2011).

Generally, in my research I made a comparison between classical optimization methods and metaheuristics.

Genetic algorithms were used in **(Duta and al., 2008 b)** to solve the problem of disassembly line balancing. The process of *disassembly line balancing* is defined as assigning a number of given disassembly tasks to a fixed number of workstations in order to accomplish the balancing of the line taking into account and the existing precedence relationships among the disassembly tasks and all the uncertainties that can occur due to the state of the product. Evolutionary algorithm was applied on the disassembly of a cell phone which components are given in figure 23.

Part No	Name	time (s)
1	Antenna	3
2	Battery	2
3	Antenna Guide path	3
4	Bolt A	10
5	Bolt B	10
6	Bolt 1	15
7	Bolt 2	15
8	Bolt 3	15
9	Bolt 4	15
10	Clip	2
11	Rubber Seal	2
12	Speaker	2
13	White Cable	2
14	Red/Blue Cable	2
15	Orange Cable	2
16	Metal Top	2
17	Front Cover	2
18	Back Cover	3
19	Circuit Board	18
20	Plastic Screen	5
21	Keyboard	1
22	LCD	5
23	Sub-keyboard	15
24	Internal IC Board	2
25	Microphone	2

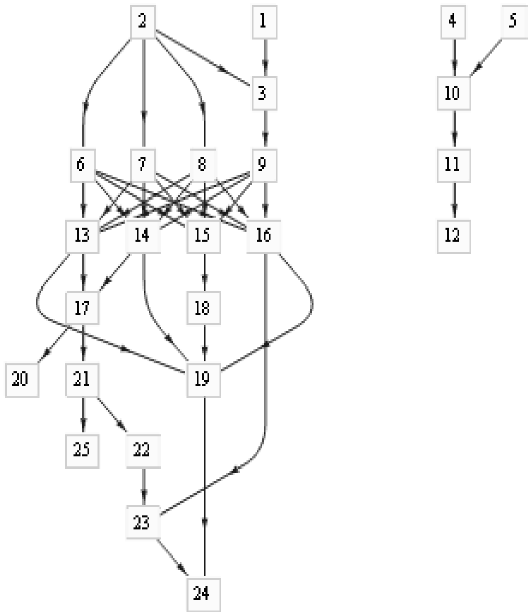


Fig. 23 Cell phone components, disassembly durations

and the precedence graph (Gupta et al. 2004)

In this work, the objective function to minimize, express the imbalance of the disassembly line:

$$f_k(t) = \sum_{i=1}^{n} \left(\sum_{j \in \{tasks W_i\}} t_j{}^k - t_{cy} \right)^2 \qquad (5)$$

Where

m number of tasks

n number of workstations

d number of possible disassembly sequences

t_{cy} the cycle time

t_j the operational time of task j

$T = \left\{ t_j^k \right\}$, *k*=1..d and *j*=1..m the matrix of the operational times for each disassembly sequence k

The matrix *S* from (4) is subjected to the following constraints:

$$s_{ij} \in \{0,1\} \tag{6}$$

$$\sum_i s_{ij} = 1 \tag{7}$$

$$\sum_{i=1}^{n} i \cdot s_{ik} - \sum_{i=1}^{n} i \cdot s_{ij} \leq 0 \tag{8}$$

$$i = 1..n,\ j = 1..m,\ k = 1..m$$

Constraint (6) is known as the *non-divisibility constraint* that does not allow a task to be assigned to more than one station. Constraint (7) is *the assignment constraint* and it requires that each task is assigned to exactly one station. Constraint (8) is *the precedence constraint* that invokes technological order so that if task *k* is to done before task *j* (k<j), then *k* cannot be assigned to a station downstream from task *j*.

After 50 iterations, the genetic algorithm indicates the minimum value of the function (5) and provides the best assignment matrix with the best fitness that balances the line. As a conclusion, evolutionary algorithms are an appropriate tool for small dimensions of the solution search space, but in real situations, solving the disassembly balancing problem involves high complexity and requires very long calculation time when the number of tasks and components grow large.

In the recycling industry, products which arrive on a disassembly line are not identical. Moreover, a disassembly line for a single type of product does not justify its costs. Thus, a disassembly system dedicated to end-of-life products must have the capacity to integrate a large variety of products from the same family. The problem of scheduling a disassembly line for family of products is treated in **(Duta et al., 2009).**

To accomplish the scheduling of the disassembly line for family of products, the Quadratic Programming method is proposed in this article and the results are tested on the disassembly process of a notebook family. A product family is a set of similar products whose main functions are identical. This means that these products are variants of a same functional product.

The variants are due to optional parts, differences among the secondary functions or between the geometrical features of the product. Function from equation (5) is transformed accordingly for a product family:

$$f = \sum_{s=1}^{K} N_s \sum_{i=1}^{n} \left(T_{cy} - \sum_{j=1}^{m_i} \varphi_{ij}^{s} \left(\theta_j^s t_j^s + (1-\theta_j^s) t'^{s}_j \right) \right)^2 \quad (10)$$

Where notations signification is:

n	number of workstations
m	number of tasks
i	index of a workstation
j	index of a task
s	index of the product type
t_{cy}	cycle time
t_j	operational disassembly time of the task *j*
t_{ij}	operational time of the task j from the workstation i

t'_j	operational dismantling time of the task *j* on the station *i*
t^s_{ij}	operational disassembly time of the task *j* on the station *i* for the product of type *s*
m_i	number of tasks accomplished on workstation *i*
S	the total number of products from the same family
K	the total types of product
N_s	number of products of the *s* type

Two decision coefficients were introduced in the objective function:

The decision coefficient θ_j that defines the operational performing manner is introduced This coefficient can take the following values:

$\theta^s_j = 1$ when the operation O_j is to be performed without damaging the product

$\theta^s_j = 0$ when the operation O_j has to be performed in a destructive way on product

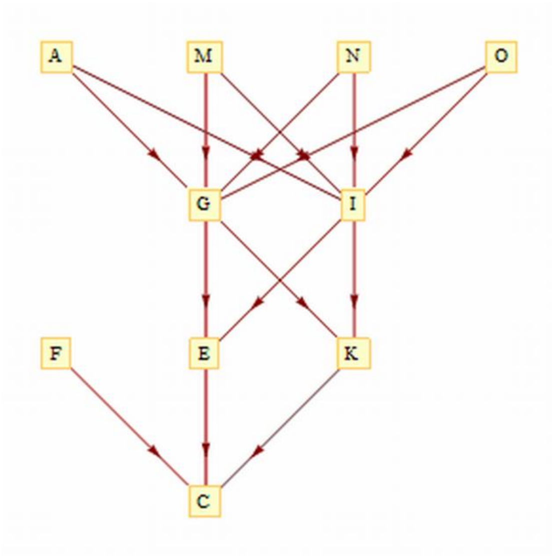
Another coefficient introduced in the objective function formula is *the assignment coefficient* φ_{ij} that defines the possible off-line assignment of the tasks to stations, for different products. It may take the following values:

$\varphi^s_{ij} = 1$, when the operation O_j can be assigned to workstation number *i*.

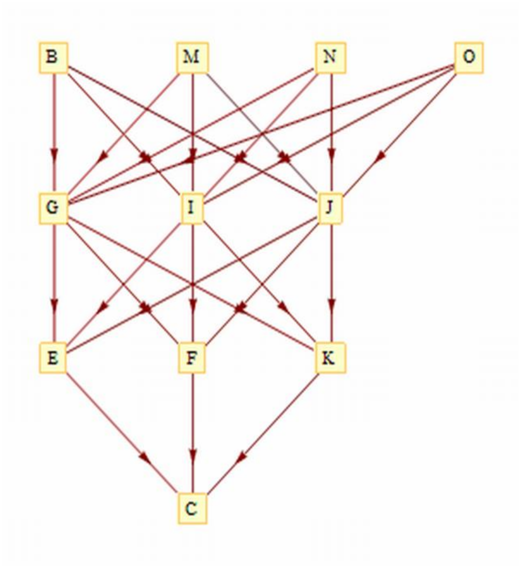
$\varphi^s_{ij} = 0$, otherwise

For the solutions computing, a *branch-and-cut algorithm* is run. The branch and cut algorithm combines the branch and bound and the cutting plane methods. Branch-and-bound algorithm builds a search tree and maintains a list of sub-problems of the linear problem relaxation that still need to be considered. The idea is to develop better upper bounds on the integer program until an optimal solution is determined. A cutting plane is a linear constraint that reduces the space of solution search during the optimization procedure. The algorithm is run on a family of four notebooks which precedence graphs are given in figure 24.

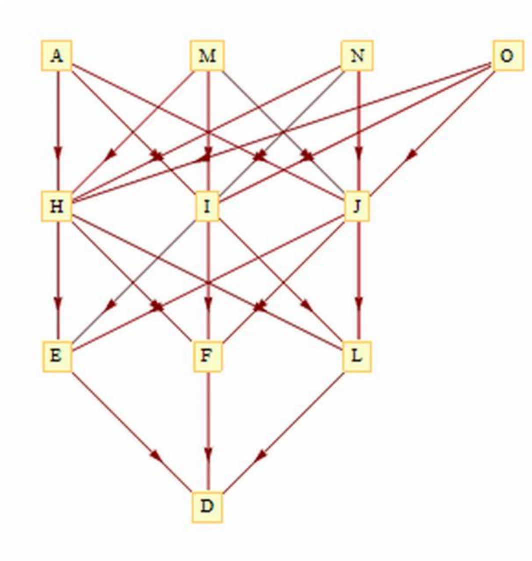
Notebook 1



Notebook 2



Notebook 3



Notebook 4

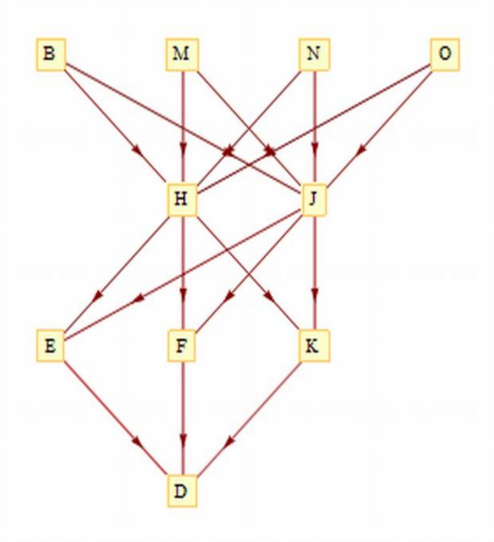


Fig 24 Precedence graphs for notebook family (Imtanavanich and Gupta, 2007).

The operational disassembly times are deterministic and known. Also the number of items from each type of notebook is given (Table 2)

Table 2. Quantity for family of four notebooks

Product	*Quantity*
Type_1	241
Type_2	261
Type_3	400
Type_4	321

The proposed solving method is to apply integer programming on a quadratic function with linear constraints. The results of simulations using XPRESS MP are given below:

```
Notebook 1
Workstation 1: A nd O nd (duration: 19)
Workstation 2: M nd N nd I nd (duration: 19)
Workstation 3: G nd E d F nd K nd (duration: 19)
Workstation 4: C nd (duration: 20)

Notebook 2
Workstation 1: A nd N nd (duration: 20)
Workstation 2: M nd O d H d I nd (duration: 20)
Workstation 3: J nd E nd F nd L nd (duration: 20)
Workstation 4: D nd (duration: 20)

Notebook 3
Workstation 1: B nd N nd(duration: 20)
Workstation 2: M nd O nd G nd (duration: 20)
Workstation 3: I d J nd E nd F nd K d(duration: 20)
Workstation 4: C nd (duration: 20)


Notebook 4
Workstation 1: B nd O nd(duration: 19)
Workstation 2: M nd N nd H nd(duration: 21)
Workstation 3: J nd E nd F nd K nd(duration: 19)
Workstation 4: D nd (duration: 20)
```

One can note that the line is well balanced: the cycle time being 20 unities. The results also show the type of disassembly operation: destructive (d) or not (nd).

A continuation of this work is made in **(Duta et al. 2011)** where the profitability of the disassembly process of the previous family of products is studied.

The profitability of the disassembly line is calculated as the product between the line efficiency (LE), the income flow of the line (IF) and the planned work horizon (H):

$$P = \alpha \cdot LE \cdot IF \cdot H \qquad (11)$$

Where $\alpha \in [0..1]$ is a coefficient which depends on the workstations' availability and its value is taken into consideration when calculating the effectiveness of the line.

The Line efficiency (LE) is expressed as a ratio between the sum of workstation operational times and the cycle time multiplied by the number of stations and the income flow is the ratio between the total profit obtained after performing a given disassembly sequence on one product and the corresponding cycle time. The Branch and bound method was applied to optimize the objective function (10) and a good balance of the line was obtained. In this case, the cycle time value is not the minimal one but is very close to it. In exchange the method provides the maximal value of the LE (=97%)

Starting from real industrial examples, **(Duta et al, 2008 c)** presents a simple-to-apply method to accomplish the balancing of complex disassembly lines in real time. Balancing a disassembly line in real time means to equalize the station loads during the disassembly process by taking into account the tasks that have not been accomplished yet and the appropriate associated disassembly strategy (destructive or not) so as complete the disassembly processing during the rest of the working time. To accomplish this optimization, a third coefficient (*a state coefficient*) was introduced in the formula of the objective function (10):

$$F = \sum_{i=1}^{n}\left[t_{cy} - \sum_{j=1}^{m}\varphi_{ij}.\psi_j.\left[\theta_j.t_j + \left(1-\theta_j\right).t'_j\right]\right]^2 \qquad (12)$$

ψ_j is *the state coefficient* that defines which operation has already been performed and which one is still to be done.

It may take the following values:

$\psi_j = 1$, if operation O_j has not still been performed

$\psi_j = 0$, otherwise.

The three coefficients have discrete values and their signification is given in Table 3:

Table 3 Real time decision variables

No	φ_{ij}	ψ_j	θ_j	Meaning
1	1	0	0	Operation j made in a destructive way on the workstation i
2	1	0	1	Operation j made in a non-destructive way on the workstation i
3	1	1	0	Operation j has to be made in a destructive way on the workstation i
4	1	1	1	Operation j has to be made in a non-destructive way on the workstation i

The balance of the line is made two times during the disassembly process and the results of simulation using Mixed Integer Quadratic Programming show that the obtained values of the cycle time and the balancing of the line are better than in the case of applying the Greedy algorithm, the heuristic research or the evolutionary algorithms (Kizilkaya and Gupta, 2006), (Gupta et al, 2004), (McGovern and Gupta, 2007).

Table 3. Comparison between the original problem and column generation problem

Tasks(n)	Machines (m)	Original Problem (MIP)		CPU (s)	Column generation (MP)		Solved nodes	CPU (s)
		variables	Con straints		variables	constrain ts		
25	9	226	85	0.78	142	101	19	0.6
45	5	226	118	0.55	184	129	10	0.3
58	10	581	149	6	363	165	1388	3
70	10	751	183	14.47	441	203	24402	12.7
111	5	556	298	7.2	441	287	545	5.7
111	10	1111	308	545.16	892	303	339837	430

The last paper presented in this category was recently accepted at the 8th IFAC Conference on Manufacturing Modelling, Management and Control (MIM 2016) Troyes France[5] **(Duta et al., 2016).** To overcome the NP-complexity of the DLBP, a heuristic methodology composed of two-stages is proposed in this article. In the first phase, a mixed integer linear model is formulated so as to integrate the disassembly task allocation constraints. In the second phase, a tree search algorithm is applied to find the optimal schedule that balances the disassembly line. Column generation is used to solve linear problems (LP) with typically huge number of variables but a reasonable number of constraints. It is mostly used for solving the LP relaxation of certain MIP problems, where the variables are not given explicitly, but by a specific structure. Instead of treating all variables explicitly, only a small subset of variables is added to the LP, the remaining variables being considered implicitly and added to the LP only when needed.

The initial MIP problem is reformulated taking into account only the columns corresponding to feasible assignments on machines, this reformulation being named the master problem (MP). During the optimization process, a branch and price algorithm is applied that leave out a set of columns of the linear problem, since there are too many columns to handle efficiently, most of them having variables equal to zero in an optimal solution.

[5] http://mim2016.utt.fr/

The reformulated problem is obtained by applying the Dantzig-Wolfe decomposition to the original problem from equations (5)-(8). A sub-problem named restricted master problem (RMP) is solved to identify columns to enter the basis. If such columns are found, the LP is re-optimized. Branching occurs when there are no columns to enter the basis and the LP solution does not satisfy integrity constraints.

The optimal solution for the MP is also optimal for the MIP if the value of the objective function from column generation is less than or equal to zero (Talbi, 2009). The proposed method reduces the number of variables, constraints and implicitly the CPU time as it is shown in Table 3. Execution time depends only of the number of generated nodes. For a reduced number of machines, the line balancing is almost perfect. As the number of workstations grows, the unbalance is higher. The inclusion of precedence constraints into the proposed model represents a significant contribution and requires an adaptation of the approach developed by Barnhart et al. (1998) on the branch-and-price solution methodology for the generalized assignment problem (GAP).

4.3. Management of Reverse Supply Chains

Reverse supply chains include collection and reprocessing activities of used manufactured products in order to recover their remaining market value. An effective management of reverse supply chain operations leads to a higher profitability of the recovering and recycling processes. As reverse supply chains have become more and more important for manufacturers, the development of new and appropriate tools and methodologies to support decision making in the operational management is necessary. Reverse supply chain management encompasses a series of activities required for retrieving a used product from customers for the purpose of disposing or reuse. Five end-of-live options (EOL) are possible for a used product: repairing, reconditioning, remanufacturing, recycling or disposal.

Repairing is the activity of replacing the malfunctioning components or modules of a product in order to establish its operating functions. Reconditioning involve disassembly operations in order to test, replace or reconditioning some parts that are non-functional or about to fail. Remanufacturing is a more complex activity that involves a complete disassembly of the product in order to replace the absent or malfunctioning parts and to restore the product to the original functional characteristics. Recycling is also a complex procedure implying the extraction of recyclable materials from the used products by operations as shredding, sorting, reprocessing, burning etc. Disposal is the last end-of-life option and is the process of landfilling or incinerating parts of the product that are not worthwhile for the other recovering operations (figure 25).

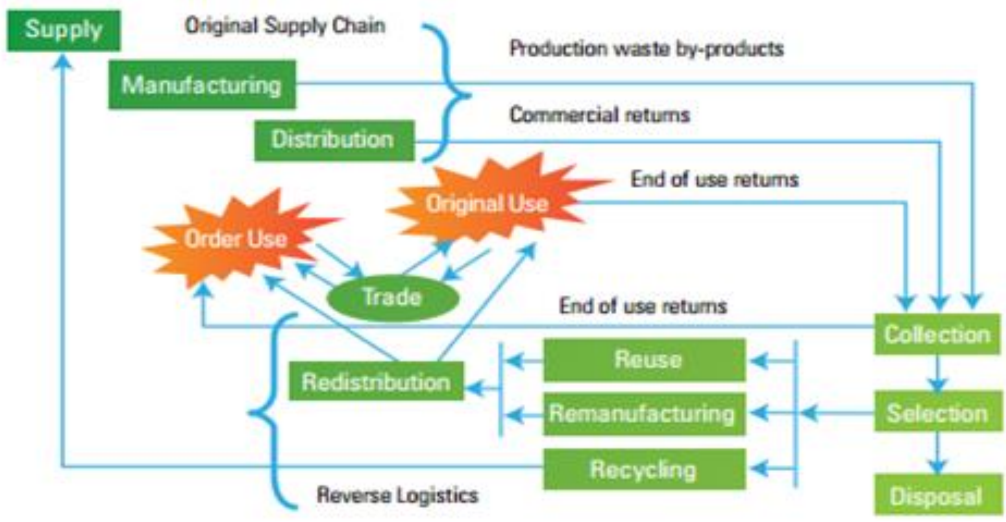


Fig 25 EOL options

All these activities need decisions at different levels: tactical, strategic or operational. In a RSC there are also decisions that concern the reverse flow management, the establishment of the inventory policies the location of the returns centers, transportation and environmental issues, etc.

The aim of this report is to underline the role of the decision support tools in supporting the reverse supply chains management making a review of international researches developed for now.

4.3.1. European legislation

Beginning with years 2000 some of the most important European directives have been elaborated and applied:

- Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles;
- Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment;

- Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment – WEEE

- Directive 2005/20/EC of the European Parliament and of the Council of 9 March 2005 amending Directive 94/62/EC on packaging and packaging waste;

- Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC;

- Dec 2008 WEEE Directive revision: possible definition of new recovery/recycling

The purpose of the WEEE Directive is to prevent the creation of electrical and electronic waste and to promote reuse, recycling and other forms of recovery in order to reduce final disposal. This Directive encourages Member States to design and produce electrical and electronic equipment (EEE) which facilitates dismantling and recovery of components and materials.

Moreover, EU proposed specific thematic and action plans to encourage green and environmentally friendly technologies and the design of sustainable supply chains. The Economic Recovery Plan of EC (2008) includes three directions: Factories of the Future (FoF), Energy efficient buildings and Green cars

Under the frame of Horizon 2020, the EU Programme for Research and Innovation, the challenge Climate action, environment, resource efficiency and raw materials includes seven calls:

- WASTE-1-2014: Moving towards a circular economy through industrial symbiosis

- WASTE-2-2014: A systems approach for the reduction, recycling and reuse of food waste

- WASTE-3-2014: Recycling of raw materials from products and buildings

- WASTE-4-2014/2015: Towards near-zero waste at European and global level
- WASTE-5-2014: Preparing and promoting innovation procurement for resource efficiency
- WASTE-6-2015: Promoting eco-innovative waste management and prevention as part of sustainable urban development
- WASTE-7-2015: Ensuring sustainable use of agricultural waste, co-products and byproducts

4.3.2. Decisional frameworks in European countries

In Germany, a study on the environmental impact in closed supply chains for EEE (Electric and Electronic Equipment) was made by Neto at al. (2010). Decision tools are proposed to analyze and measure the magnitude of the environmental impact. The paper proposes a multicriteria decision-aid (MCDA) approach to aid the decision-maker in selecting the best end-of-life alternatives. As a conclusion, authors stated that sustainability can be obtained by changing the objectives from economy driven towards economy, environment and society driven.

In Poland, a reverse logistics model that uses reliability theory to describe the reusability of parts in production process was implemented (Pelwa et al., 2012). The model allows estimating the potential profits of the reusing policy in a production and gives the basis for optimizing some parameters: the threshold work time of returns, the warranty period for products containing reused elements.

In Lehtinen et al. (2006) is presented a case study of how collection of WEEE was organized in Northern Finland. The study also shows that the real challenge of collection lays in separating the reusable equipment are from the non-reusable ones, then sending both to the adequate treatment operations. All procedures are monitored by a Waste Management Company located in Oulu.

A conceptual framework is presented in Aidonis et al. (2008), on the current status and legislation in the field of construction and demolition waste management in Greece. An integrated decision-making model for the construction and demolition supply chain is proposed starting from the deconstruction and demolition operations through the transportation of the collected materials to the potential recyclers and disposal sites.

A methodology for solving problems of inventory management for recovered arts in the aftersales automotive industry in Croatia is presented in Tomasik et al. (2013). Authors underlined the main key points in a reverse supply chain for automotive sector: the service center, the local logistics center, the logistics center of spare parts, and the manufacturing site. A Delphi questionnaire was elaborated to ask managers from the automotive sector what are the most critical actions in a reverse supply chain. Based on managers' answers, the overall opinion is that there is insufficient use of IT solutions provided by car manufacturers for managing spare parts inventory. Also based on interviews with responsible persons from post sales points can be seen of the need to increase the sale of recovered spare parts. With the implementation of supporting information technology, it is possible to ensure changes in the reverse logistics and spare parts inventory and to increase the awareness of the consumers.

Maudet and Bertoluci (2007) proposed a decision aid tool for plastic recycling in the automotive industry. Authors described a dynamic model based on a systemic approach taking into account effects of interactions between all reverse supply chain actors from the dismantler to the spare parts market and implemented a knowledge based approach to standardize the use of recycled plastics in automotive sector.

In Denmark a decision support system based on a metaheuristic approach for performance measuring of the RSC was elaborated (Kannan, 2009). In Spain, a decision support system for a recovery management framework was developed by Fernandez et al. (2008). A fuzzy logic module was used to analyze a high number of input factors and the output. The decision system gives a score to each proposed recovery policy and makes an analysis of the sensitivity of the recovery policies for different scenarios according to the variations of the input variables. Applying the proposed decisional fuzzy system in practice the advantages are: a decrease of the returned products in the inventory levels, a reduction in decision times, shorter handling times, and fewer risks of degradation of the product.

In Estonia, software for decision aid in the recovery of spacecraft circuit boards was proposed (Shevtsenco and Wang, 2009). This software is based on the implementation of artificial intelligence by means of the Bayesian networks.

In Turkey, researchers developed and implemented a multi-criteria decision making model for advanced repair-to-order and disassembly-to-order system (Ondemir and Gupta, 2014). The proposed system optimizes four performances RSC: the total cost, number of disposed items, the material sales revenue, and customers' satisfaction level to be optimized. The proposed system was designed so as to include the newest information technology devices that were utilized to reach the optimum disassembly, repair, disposal, recycling and storage plans.

Preoccupations in implementing decision aid tools and decision support systems in reverse supply chain design and management also exist in the outer European space, in countries as Canada, USA, India, China and Japan. Therefore, future European projects will encompass researches from all over the world that are concerned about green technologies and reverse supply chains architecture design.

4.3.3. Preoccupations in Romania

In Romania, recycling or recovering actions have started recently, so as the recycling rate is still low (about 2%). Therefore, an important national effort of all stakeholders, environmental agencies, ONGs and regional responsibles is necessary so to meet the European Union requirements of 50% rate of waste recycling by 2020.

In 2013 there were five big recycling companies located on the Romanian territory1:

- Greentech SA an important plastic recycler from South-Eastern Europe and also a pioneer for plastic waste recycling in Romania.

• Greenfiber International is the only producer of synthetic polyester fiber from Romania and the second largest European producer of polyester synthetic fiber.

• GreenWEEE International SA is the biggest treatment plant for electric and electronic equipment waste (WEEE) in Romania and one of the most modern in Europe.

• GreenLamp Recycling SA is the only recycler in Romania which is using an in-house distillation process in order to separate fluorescent tubes components

• GreenGlass Recycling S.A. is the most important glass recycling plant in Romania.

The National Waste Management Strategy developed in 2003 was intended to cover a ten years period. In 2004, the National Plan for Waste Management was developed and in 2006 Regional Plans emerged so as to increase the efficiency of the National Plan implementation.

The municipalities are responsible for the collection and management of municipal solid waste. This waste was collected 84 % from the urban areas and only 38 % from rural areas. The evolution of collected and treated municipal waste quantities is not increasing constantly. Two peaks were registered noticed: in 2002 with approximately 6 865 000 tones and in 2008 with 6 561 000 tones (Almasi, 2013). Approximately 300 million euros from European funding has been assigned to improve the waste management in Romania **(Larive, 2011).**

A team of researchers from Valahia University, Romania in collaboration with Dacia-Renault Enterprise is developing studies on Reverse Supply Chain Inventory for the automotive sector (**Duta et al, 2014**). A national project proposal is in development in the frame of PNII Ideas Challenge, to put the basis of a Collaborative Decision Platform for all the automotive manufacturers and dismantlers in the country. This platform will facilitate connections between the main stakeholders from the automotive supply chain, and group decisions concerning the operational flow from collector through warehouses, to dismantlers or recyclers, to spare parts vendor and clients of secondary market.

4.3.4. Decision aid in reverse supply chains

The introduction of reverse logistics in supply chain management has created new decision-making dimensions. Consequently, parameters that may affect the operation of reverse supply chains should be evaluated. In this chapter, a qualitative approach has been discussed with respect to such parameters, aiming at facilitating and augmenting decision-making in reverse supply chains. In such cases, several stakeholders get involved, including governments, producers, distributors, and customers. As a result, decision-making procedures get more complicated due to increased levels of conflicts of interests but also due to practical reasons. For example, it is not always easy to get all stakeholders together in a round table. As it has been illustrated in this chapter, ICT may support decision-making procedures in conflicting environments by providing the means to structure dialogue, disseminate information, and last but not least, facilitate the associated reasoning process.

As decision aid tools used in literature for the decisional framework development and the management of the RSC, one can find fuzzy multi-attribute decision making, MCDM methods (AHP, ANP, ELECTRE), Bayesian Networks, stochastic Dynamic Programming, Markov chains, Mixed Integer Linear Programming, decisional analysis under uncertainty, meta-heuristics, genetic and evolutionary algorithms (**Gupta, 2010).**

Risk management is the structured approach of identifying risk, quantifying the likelihood of its occurrence, and measuring its potential effect on the business. Risk management encompasses three processes: risk assessment, risk mitigation, and evaluation and assessment (Stoneburner et al, 2002). Risk assessment is the first process in the risk management methodology. Organizations use risk assessment to determine the extent of the potential threat and the risk associated with the system. Risk mitigation is the second process in the risk management methodology. It involves prioritizing, evaluating, and implementing the appropriate risk-reducing controls recommended from the risk assessment process. In ideal risk management, a prioritization process is followed whereby the risks with the greatest loss and the greatest probability of occurring are handled first, and risks with lower probability of occurrence and lower loss are handled in descending order. In practice the process can be very difficult, and balancing between risks with a high probability of occurrence but lower loss versus a risk with high loss but lower probability of occurrence can often be mishandled. A successful risk management program relies on senior management commitment and the competence of the risk assessment team, which must have the expertise to apply the risk assessment methodology to a specific system. The ability to identify risks and providing cost-effective safeguards that meet the needs of the organization are essential in risk management.

There are a number of risks and uncertainties associated with the reverse supply chain and recovering used material from consumers. These risks are related to timing, quality of returned products, quantity of returned products, and variety of returns (Srivastava, 2008). There are also risks involved with consumer behavior and preferences. Additional risks include estimating asset value, cost of operations, and decision making for product returns along the reverse supply chain. One of the greatest challenges of reverse supply chain is the uncertainty associated with product returns. This uncertainty allows room for numerous risks in the reverse supply chain which makes forecasting and planning returned products a challenge. There is room for improvement to minimize cost and create an efficient reverse network. In order to improve the reverse supply chain and minimize costs, a thorough analysis of risk minimization must be performed. The reverse supply chain requires the establishment and implementation of new performance measurement systems and risk analysis model.

Risk assessment is the first process in the risk management methodology. Organizations use risk assessment to determine the extent of the potential threat and the risk associated with the system. Wang et al. (2008) proposed a new integrated AHP-DEA methodology to evaluate the risks of hundreds or thousands of bridge structures. The proposed methodology uses analytic hierarchy process (AHP) to determine the weights of criteria linguistic terms such as High, Medium, Low, and None to assess bridge risks under each criterion, the data envelopment analysis (DEA) method to determine the values of the linguistic terms, and the simple additive weighting (SAW) method to aggregate bridge risks under different criteria into and overall risk score for each bridge structure. The integrated AHP-DEA methodology is applicable to any number of decision alternatives and particularly useful to complex multiple criterion decision making (MCDM) problems with a large number of decision alternatives, where pair wise comparisons are difficult to make. A numerical example was investigated to illustrate the application of the methodology. Shyur (2008) proposed a new quantitative methodology for the assessment of risk in civil aviation. The spline method is used to present the baseline hazard function. This approach allows finding fundamental cause of human error related accidents through the analysis of operational safety data. The model takes into account the relationships among relevant aviation risk factors such as human, technical, environmental, and organization factors that affect safety and system performance. The results of this case study demonstrate that the proposed model is a more promising regression model with the potential of becoming very useful in practice and leading to further generalization of aviation risk analysis.

Kunene and Weistroffer (2008) have developed an approach that seeks to incorporate prior knowledge about broader decision objectives into the data mining process using multicriteria decision analysis. Their approach has the desirable effect of letting decision objectives drive data reductions. They applied decision tree induction from data mining analysis, to a knowledge-enhanced database and employed a multicriteria decision analysis method as well as rule-based systems, to analyze and structure the prior knowledge about the patients in definitive care. The research performed can be further developed with the intention of expanding the decision structure and collecting data that is currently unavailable electronically or data that is recorded in other areas and departments of the organization.

In **(Filip and Duta, 2015)** role of pacing technologies in supporting RSC decisions was underlined. Thus, the Agent Technology has proved to be suitable for simulation of the dynamic configuration of the reverse supply chains. Agents collaborate one with another to perform multiple and synchronized tasks.

Cloud Computing (CC) Technology has provided efficient solutions for improving the management of forward and backward operations in a supply chain. CC facilitates on-demand access to a large quantity of data or information and to network functionalities with a minimal management effort and service provider intervention. The advantages of this technology are clear: easy installation of new software releases, paying per service, broadband penetration, facilitated by the new web technologies. However, there are still problems to solve like data security and protection, difficult customization for large applications, latency of systems.

Big Data Technology can help companies to manage large volumes of data, to make real time analysis of data from a variety of data structures. Incorporating big data into the reverse supply chain management improves the enterprise ability to correlate systems' data in real time, managing the chain inventory while respecting environmental and economic regulations. Big data can help maximizing the recovered value of a used product through a greater depth of information about specific operational times and options in a reverse supply chain. Big Data in conjunction with the required sustainability and responsibility with regard to its use gave birth to a new term "Datability" (CeBIT, 2015)

Cyber Physical Systems (CPS) are "engineered systems that are built from and depend upon the synergy of computational and physical components" (NSF 14-542). CPS have applications not only in smart grids, smart buildings, or smart transportation but also a great impact on advanced green manufacturing. Thus, the development of advanced integrated computer-based systems for green manufacturing may be placed into Cyber- Physical Systems movement.

Duta et al. 2014 proposed a mathematical decisional model to deal with the stochastic aspect of the reverse supply chain inventory. Decision variables are introduced on two levels: a proactive level and a reactive level. To implement the proposed model, Bayesian Networks were used so as to determinate all influences and causalities between decision variables. The results show how information influences decisions and how these decisions cause the change of information.

The economic order quantity model (EOQ) is one of the most widely known inventory control methods. It is used to set the quantities to order in replenishing inventories so that a trade-off between inventory holdings and ordering/set up costs is achieved. Some assumptions are associated with this model: a) constant and known demand, instantaneous receipt of inventory, b) constant and known time intervals between order placement and receipt of the order, stock outs are avoided by placing orders at the right time. It is also assumed that the unit procurement price remains constant irrespective of the number of units purchased. This model induces four inventory basic policies according to the moment of the inventory position review: with continuous review or with periodical review. Used notations: Q = order quantity, S = order-up-to level, s = reorder point, T = review period.

The (s, Q) policy: Whenever the inventory position (inventory level plus quantity on order) drops to a given level limit, s, or below, an order is placed for a fixed quantity, Q.

The (s, S) policy: Whenever the inventory position (inventory level plus quantity on order) drops to a given level s, or below, an order is placed for a sufficient quantity to bring the inventory position up to a given level, S.

The (T, S) policy: Inventory position is reviewed at regular discrete time moments spaced at intervals of length T time units. At each review, an order is placed for a sufficient quantity to bring the inventory position up to a given level, S.

The (T, s, S) policy: Inventory position is reviewed at regular instants spaced at time intervals of length T. At each review, if the inventory position is at level s or below, an order is placed for a sufficient quantity to bring the inventory position up to a given level S. If the inventory position is above s, no order is placed.

When T=0 in the (T, s, S) policy, one obtains the (s, S) policy. So, the (T, s, S) policy can be regarded as a periodic version of the (s, S) policy, which, in turn, may be viewed as a special case of the (T, s, S)

The (T, S) policy represents a special case of the (T, s, S) policy in which s = S

Since the demand for spare parts is variable and is depending on the needs and the time when an order for replenishment is placed until the replenishment arrives (the lead time), the (T, s, S) policy was considered in this paper. In such a system, the period of review is fixed and the ordered quantity changes as per demand or rate of consumption. The period of review T is decided such as the ordered quantity is economical for purchasing the items.

The problem is to coordinate the two processes - disassembly and remanufacturing - so as to meet the demand of items. Another problem is the disassembly depth that deals with how completely a product should be disassembled. In this context, the researcher must weigh not only the costs of the process, whether is destructive or not, but also consider which reusable parts are already in stock, how many will be obtained through disassembly and will be accumulated in inventory and how many parts will have to be disposed of. It is obvious that a reverse chain inventory model has to include different decision variables.

In the model the following notations were utilized:

N_i^d = Number of items i to acquire and disassemble

P_{ki} = Amount of part k in item i

P_{ki}^r = Amount of part k in item i to reuse

P_{ki}^d = Amount of part k in item i to dispose

P_{ki}^h = Amount of part k in item i to hold (to stock)

C_i^a = Acquisition cost of the item i

C_i^d = Disassemble cost of the item i

C_k^r = Reusing cost of the part k of the item i

C_k^d = Disposal cost of the part k of the item i

C_k^h = Holding cost of the part k of the item i

P_{sc} = Probability of scenario sc occurring

TC = Total inventory cost

To simplify the analytical model, the following assumptions are made:

- Only a single type of product to disassembly is considered
- There is no lead times for acquisition or disassembly
- EOL items to disassembly are always available
- A single disassembly scenario (=1) is occurring
- Products are completely disassembled

- There are only two types of EOL options: reusing and disposal
- Two types of disassembly operations are considered: destructive and non-destructive
- All costs are deterministic and constant
- The interval to acquire is deterministic (at the first slice of time t)
- The amount of reusable, disposable and holding parts is subjected to uncertainties
- The number of items to acquire at the second slice of time have a probabilistic distribution
- The model is periodically reviewed

To implement the model, Bayesian Networks were used so as to determinate all influences and causalities between decision variables. The results will show how information influences decisions and how these decisions cause the change of information.

Bayesian networks (BN) have the ability of capturing both qualitative knowledge through their network structure, and quantitative knowledge through their parameters [14]. A static Bayesian Network can be extended to a Dynamic Bayesian Network (DBN) by introducing relevant temporal dependencies to capture the dynamic behaviors of the system at different moments.

To validate the model, the BayesiaLab® software is used; The software is able to seize degrees of probability. Once validated, probabilities are used jointly with the probability distribution for giving a new Probability distribution. BayesiaLab® allows the temporal dimension integration in a Bayesian Network. Thus, a BN can be easily transformed into a DBN. Temporal nodes at instants t and t+1 can be represented and connected by temporal arcs. The parameters evolution of the DBN nodes can be so tracked in time.Decision nodes are marked by squares. The amount of part k found in item i influences the amount to reuse, to dispose or to hold. Further, these decisional variables change the number of products to be acquired at the next slice of time (moment t+1). The two temporal nodes Nid(t) and Nid(t+1) are linked by a temporal arc. Figure 26 shows background calculation of the total cost. The objective function is included in the utility node TC. In the figure, two decision nodes are represented: Da – decision to acquire used products, Dd – decision to disassembly.

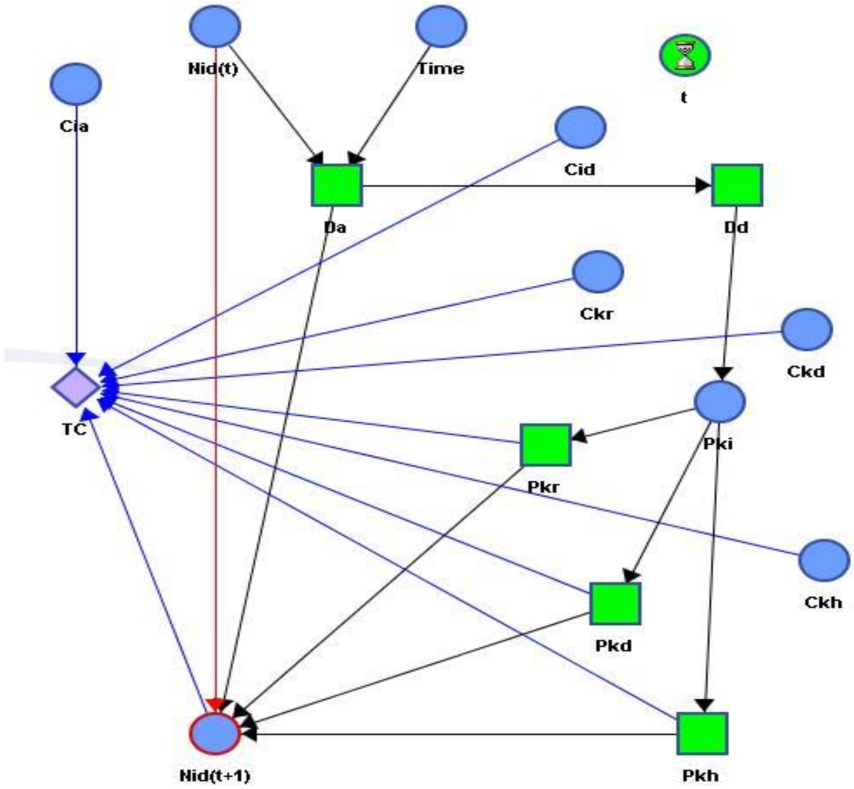


Fig 26 Dynamic Bayesian Network for preventive and reactive decisions

The total cost of the disassembly phase (TC) is composed of product acquisition cost, disassembly operations costs, EOL options costs and inventory cost. The value of the total cost is given by the equation (1). The first term is the cost of product acquisition and disassembly so as to meet the demand of parts for remanufacturing, while the second term is the inventory cost of the disassembled parts. This function is a multi-objective one, since the aim is to find not only the optimal quantity of products to acquire to meet the demand of parts, but also to find the best EOL strategy or scenario so as to optimize the number of parts to reuse in a remanufactured product. For the moment we are interested on quantity to acquire to meet the demand, while scenarios probabilities are introduced by the software to reduce the objective function to a mono-objective one.

The objective function to be minimized is:

$$Min(TC) = Min(\sum_i (C_i^a + C_i^d) \cdot N_i^d + \sum_i \sum_{sc} P_{sc} (C_k^r \cdot P_{ki}^r + C_k^d \cdot P_{ki}^d + C_k^h P_{ki}^h)) \quad (1)$$

In equation (1) the unknown variables are

$N_i^d, P_k^r, P_k^d, P_k^h$

The objective function is subjected to the following constraints:

$$d_k \leq \sum_i \sum_{sc} P_{sc} \cdot (P_{ki} - P_{ki}^d) \quad (2)$$

$$N_i^d \geq 0 \text{ and integer} \quad (3)$$

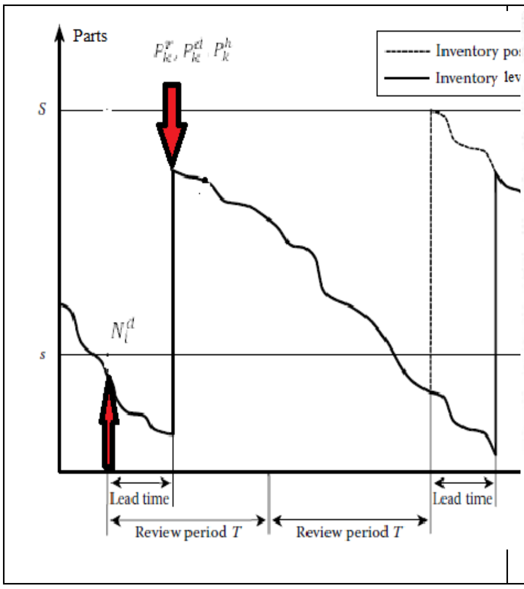
$$P_{ki}, P_k^r, P_k^d, P_k^h \geq 0 \text{ and integer} \quad (4)$$

$$\sum_{sc} P_{sc} = 1 \quad (5)$$

Where is the demand (the number of k parts needed). One can note that equations (1) to (5) form a linear integer mathematical model where decision variables can be treated as continuous in order to satisfy the integer value of the demand.

Computations were performed with the help of FICO XPRESS® optimization tool which provides a mixed integer solver and framework for constraint integer programming. Supposing a periodic review inventory with a security stock at the beginning of the period, the classical (T, s, S) policy is modeled in figure 27. The planning horizon was fixed to a month, and the review period is established to ten days. Results show that at the end of each review period, the number of disassembled products arrives to a minimal value and the TC to a maximal one. For the EOQ model with constant demand, a decision to acquire products to disassemble is taken whenever the inventory level reaches the reorder point (figure 28).

Running simulations on the previous model, the decision to acquire is taken before the beginning of each new review period. In other words, starting with a periodical review inventory model, which usually provides orders at constant periods of time, we have reached to a mixed model where orders are given in accordance with the reactive decisions (i.e. in real time).



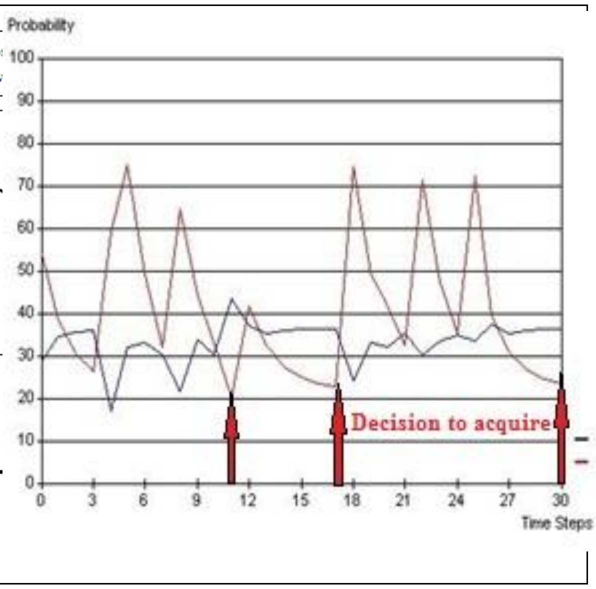


Fig. 27. (T, s, S) policy decisions

Fig. 28. Reactive decisions moments

Proactive decisions aim to determine the initial number of items to disassembly to fulfill the demand of parts. Reactive decisions take into consideration disassembly scenarios and the end-of-life options of the disassembled parts. The model optimizes the quantity of used products to acquire so as to minimize the total inventory cost. Future work will integrate the results above in a decision support system. This issue needs further investigation in real-world settings where the increased cognitive complexity of using different models (i.e. DBN, integer programming), most likely by a collective decision-maker, will play a major role in adopting the proposed solution.

Complex decision theory is useful to solve problems and demonstrate sustainability and integration solutions for green technologies. There is a continuous need of conscious environmental manufacturing and people education for sustainability. In the same time, in the frame of European and governmental initiatives there is still a strong need of national standards, policies and pilot projects. The emergent technologies as cloud computing, agents, big data and cyber physical systems will influence the design of supply chain infrastructures and the management solutions. More collaborative decision systems with special functionalities and capabilities to support variability and uncertainties that usually occur in a reverse supply chain management are needed. All these subjects are real challenges for the environmental researchers, engineers and economists.

PART II

PROFESSIONAL DEVELOPMENT PLANS

Chapter 5
General guidelines for further developments

5.1. Scientific research subsequent development

There are some general characteristics that will guideline my future professional and scientific development. My logic, my curiosity, the sense of observation, my creativity and objectivity are several characteristics that will allow me to continue the research work with success.

To maximize my expertize in terms of knowledge and experience and to facilitate the know-how transfer, as soon as I get the Habilitation Degree, I will propose *three new research topics* for the PhD students in Systems Engineering from the Doctoral School of Ploiesti University:

1. Planning and control of the reverse supply chains, especially those dedicated to WEEEs; Production planning models and management techniques to deal with the uncertainties occurring into RSCs for electric appliances and automotive industry will give birth to many PhD subjects of research; in the same time, metrics and decision aid tools must be proposed in order to measure the performance of a RSC;

2. Optimization techniques for remanufacturing planning and scheduling; new optimization techniques bio-inspired must be exploited to plan and schedule jobs in disassembly to order, reassembly or remanufacturing systems; one subject that challenges the researcher is the real time scheduling of the disassembly and reassembly lines, a NP-hard problem that haven't been solved yet;

3. Design and implementation of decision support systems for preventive maintenance; the objective of this research is to develop mathematical and graphical models for the real time scheduling. Most of the maintenance systems operate in dynamic environments subjected to different events, which can make the corrective maintenance neither feasible nor optimal. The goal is to pass from the corrective maintenance to the preventive one. The dynamic scheduling is of a great importance for the implementation of real production systems. Consequently, I intend to develop algorithms to face the reactive programming under the constraints of availability of human resources.

Some project proposals are in elaboration. One of the projects at the European scale intents to develop and implementation of a collaborative Web platform dedicated to stakeholders, SMEs, environmental agencies etc., where each actor can define his strategic actions and/or research in waste prevention and management. The platform is designed to be an efficient decision support for an EU network of relevant institution concerned with waste technologies and waste legislation. The collaborative platform will also provide a personalized space to each stakeholder that will be engaged in the cooperation and communication process. The platform’s shared interface will contain a webmail, a forum, a multimedia section, a report section and a real time map of the active participants.

At the national scale, another project objective is to put in contact all WEEE recyclers and to establish a national network for collectors, disassemblers, recyclers and re-manufacturers of used cars. The web platform will give access to each actor and will allow decision making and information management in the automotive reverse supply chain.

When I write this thesis, together with a European group of researchers, I’ve submit a new proposal in the frame of COST European Actions. The title of proposal is *“Collective Decision Making and Computation”* and it focuses on fundamental novel challenges in mechanism design and computational analysis in collective decision making. Collective decision making applications cover areas as multi-agent resource allocation, online tools for group decisions, social networks, e-commerce and web page ranking algorithms. This action will focus on its algorithmic and computational aspects and will provide a collaborative platform for researchers working in computational social choice and game theory.

To maximize the international impact of my work, I intend to publish my future work in Journals with important impact factor as *International Journal of Production Control*, *Journal of Manufacturing Systems* or *International Journal of Production Economics*. I have already started the work on a literature review on the reverse supply chains management frameworks. I hope that in the future, the number of my citations will increase exponentially, since the interest on the remanufacturing and reverse logistic management and control is in continuous growth.

To maximize the international institutional visibility of my University and Faculty, the research activities must be related with the strategic development plan for Horizon 2020. That means to strengthen the collaboration between researchers and colleagues of my department and to work together to European projects proposals.

To increase the visibility of my research group, I have designed a web page dedicated to the *DSS Group Romania*[6]. This is a team of young members from different Romanian universities and research institutes, which has as main goal the research in the field of decision support systems. The groups' objective is to create a core of researchers from several Romanian universities whose works and publications are oriented towards the study and implementation of DSS in finance, industry, environment protection and transportation. The members of the DSS Group Romania have already attended and organized invited sessions and thematic conferences and will continue to participate to European research actions.

[6] http://ssd.valahia.ro/

5.2. Development plans for didactic activities

On the didactic plan my objective is to strengthen the relations with industry stakeholders so as to create collaboration opportunities and internships for students. It is very important for a student to gain practical abilities and expertize, since being engineer means to solve real and pressing problems from industry using the knowledge accumulated in the university.

As the faculty responsible with international relations, another objective is to intensify the ERASMUS exchange of students. We have already a lot of ERASMUS collaborations with some European universities, in which our students can be educated and instructed using modern laboratories and technical resources. In this way they will be prepared for the work on the European framework.

I will continue to contribute to the enhancement of the specialty program and to propose new lectures on subjects as: *"Optimization techniques in manufacturing"*, *"Forward and reverse logistics*", - for the master program and *"Web programming"* – for the 3th year of study. These lectures that are necessary to automation engineers but they are still not provided by the program of study.

I will keep trying to improve my pedagogical skills and support stude nt involvement in learning and research.

PART III

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